Soil Erosion in Relation to Vegetation on Certain Soil-Type Areas in Arizona and New Mexico

by

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Contents

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Illustrations

Introduction

Many exposures of unproductive subsoils, marls, rock strata or other soil-forming materials are found in the Southwest. On such exposures there is usually little or no vegetation. On other areas, soils, although shallow and underlain by soil-forming materials similar to those found on the exposures, support a cover of herbaceous vegetation. This cover varies as to proportionate composition of plant species and as to the percent of ground surface it covers. On some of the areas which have a covering of soil and vegetation, eroded surfaces show that some of the top soil has been washed away; on others there is no visible evidence of soil erosion. Observation of these conditions prompted the initiation of the study of the relation of soil erosion to herbaceous vegetation on certain soil-type areas in Arizona and New Mexico.

As a basis for the consideration of such a study we must first have some conception of the nature of soil, rate of soil formation, influence of soil and vegetation on soil erosion and the influence of physical and biotic factors on vegetation.

The soil, that thin mantle of decomposed rock and plant residue which covers the land areas of the earth and supplies mechanical support, and, in part, sustenance to plants, is continually changing. It is the product of the natural forces which have been active over long periods of time.

Excerpts from "The Great Soil Groups of the World and Their Development", (page 9), by Prof. Dr. K. D. Glinka, Director of the Agricultural Institute at Leningrad [6], give us some idea of the modern concept of soil formation.

> "It should be remembered that we designate as soil the products of weathering which remain in the place where weathered. It must carry the impression of all inner and outer forces which have taken part in its formation. In the morphology of the soil type the climatic conditions of the locality, the combined effect of moisture and heat, the essential features of vegetation and the character of the parent rock all find expression. Each of these factors constitutes a part of the soil formation processes.........."

The rate of soil formation is exceedingly slow. Bennett (1 - page 21) quotes from an address by T. C. Chamberlain, before the Conference of the Governors of the United States, in 1908, as follows:

> "We have as yet no accurate measure of the rate of soil production. We merely know that it is very slow. It varies obviously with the kind of rock. Some of our soils are derived from material already reduced to a finely pulverized condition. Such are the lowland accumulations from highland wash. Such also is the glacial drift, rock flour rasped from the face of the ledge by the glacial file, and ground up with old soils. On such a base of half prepared material, soils may be developed with relative rapidity; but even on these, when the slope is considerable, wind, wash, and cropping remove the surface much too fast for stability......... Without any pretensions to a close estimate, I should be unwilling to name a mean rate of soil formation greater

than one foot in 10,000 years, on the basis of observation, since the glacial period. I suspect that if we could positively determine the time taken in the formation of the four feet of soil next to the rock over our average domain, where such depth obtains, it would be found above rather than below 40,000 years. Under such an estimate, to preserve a good working depth, surface wastage should not exceed some such rate as one inch in a thousand years".

The soil mass in a non-eroded state supporting a cover of vegetation and plant litter is a medium affording optimum conditions for plant growth and for infiltration and percolation of rain and snow water. When a portion of the soil mass is removed by erosion, its capacity to absorb rainfall run-off is impaired. Lowdermilk [(7)] of the U. S. Soil Erosion Service found that destruction of forest litter and the consequent exposure of the soil greatly increased the amount of eroded material carried off by wash and reduced the water absorption rate of the soil. This reduction, he found, was due to suspended particles in run-off water from bare soils which filtered out at the surface and sealed the pores and seepage openings in the soil.

A reduction in the density of vegetation [1] covering the soil results in increased rainfall run-off and erosion. An increase in density of vegetation results in decreased rainfall run-off and erosion.

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1 The term, density of vegetation, as here used may be defined as the percent of ground surface covered by vegetation. If vegetation covers 50 percent of a ground surface, the density is 50 percent.

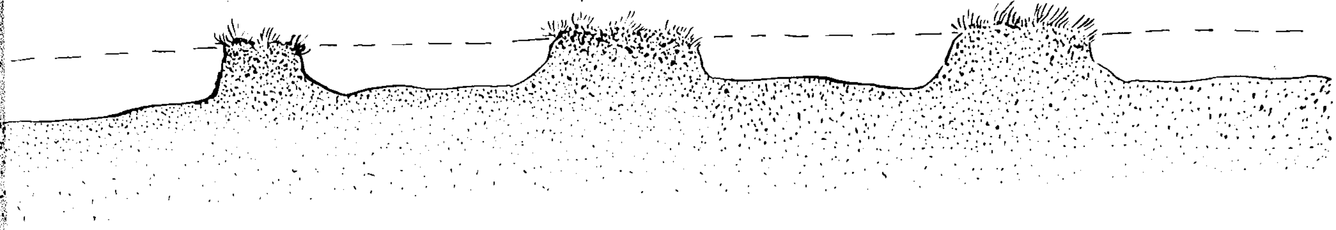
Forsling [5] in a study of the influence of herbaceous plant cover on surface run-off and soil erosion in relation to grazing on the Wasatch Plateau in Utah found that an increase in the density of vegetation from 16 to 40 percent of a complete ground cover and the replacement of certain plants by others with more extensive root systems reduced the rainfall surface run-off 64 percent and rainfall erosion 54 percent.

Experiments carried out by Dudley and Miller [4] on Shelby loam soil in Missouri show that erosion from bare, uncultivated soil was 125 times as much as the erosion from a soil surface covered by a dense blue grass sod.

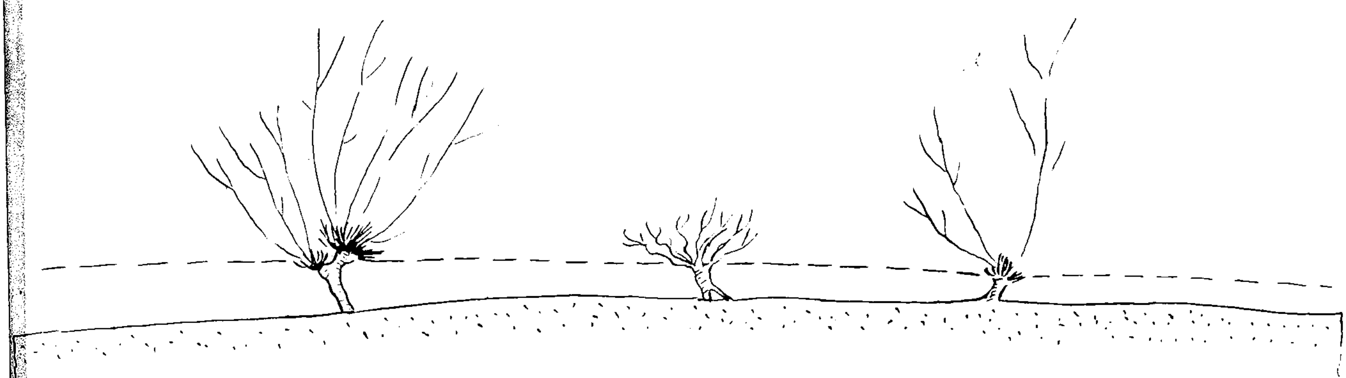
Soils which have been eroded have certain surface characteristics differing from those of soils that have been undisturbed by erosive processes.

Cooperrider and Hendricks [3] in a report on condition of plant cover, erosion and stream flow on the Rio Grande Watershed above Elephant Butte Reservoir describe the character of eroded soils. They found that by close observation of eroded soils they were usually able to detect pedestal-shaped humps or mounds of finer, more productive soil under bushes, large grass tufts, half shrubs or other vegetation, while the surface in the open, except on level ground, was at a lower level. If rock, gravel or rubble was a constituent of the underlying soil mass there was a distinct paving or litter of such material on the eroded surface. Such paving is formed by the accumulation of rock, coarse grained gravel or rubble on the surface as the fine soil is washed away. A heavy litter of loose rock on the surface over a soil containing a low proportion of rock or coarse material to fine soil is usually quite indicative of the amount of soil carried away by run-off.

These earmarks of accelerated erosion are usually visible despite the many influences which tend to obscure their presence. In the first stages of soil erosion, pedestal-shaped soil humps are miniature and paving is negligible and only by close observation is loss of valuable top soil detected. As erosion increases pedestals become prominent, shoestring gullies appear, the ground surface is corrugated. Surfaces held in place by vegetation about equal surfaces stripped of top soil by wash. As erosion continues at an accelerated rate more of the ground surface is lowered. The paving of rock and coarse material increases. Many of the soil humps are eroded away. Eventually, except for rock and gravel accumulations, deep gullies and occasional humps or mounds of soil beneath persistent perennial grass tufts or shrubs the evidence of accelerated erosion is removed and little remains of the original top layer of productive soil.



Soil Pedestals Held by Grass Roots



Exposed Roots of Half Shrubs

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Soil mounds Underneath Shrubs

Examples of Visible Soil Depletion

Figure 1

A

Exposed roots of a short lived perennial, Eriogonum inflatum, are indicative of depth to which soil has been removed by erosive agencies within a relatively short period of time. (Photo by U. S. Forest Service.)

B

Rock exposure on this slope is evidence of extreme loss of surface soil, erosion having exposed the unproductive sub-soil. Underneath shrubs can be found remnants of productive soil. Soil is also slowly built up underneath larger shrubs. (Photo by U. S. Forest Service.)

Figure 2.

A

Persistent grass clumps have held pedestal-shaped humps of soil while remainder of upper soil layer has eroded away. Height of humps indicates depth to which soil has been eroded. (Photo by U. S. Forest Service.)

B

A snakeweed cover and heavy rock litter is indicative of loss of herbaceous cover by overgrazing and loss of soil by erosion. A shallow layer of top soil covers a deep layer of unproductive sub-soil. (Photo by U. S. Forest Service.)

Figure 3.

From the presence of soil pedestals and exposed root crowns of shrubs or trees it is often possible to reconstruct with reasonable accuracy the past profile and to measure the amount of soil loss. (Figures 1, 2 and 3.)

Areas on the Rio Grande Watershed (3) on which soil erosion was evident in moderate degree supported on the average a cover 2-3/4 times as dense as the cover on areas where erosion was extreme. On non-eroded soils a good density of cover was found. Soils were friable and spongy; not packed. Leaf duff or grass litter was usually present. On eroded areas plant litter was usually lacking or confined to that beneath shrubs.

Sampson and Weyl (8), conducting experiments at the Great Basin Experiment Station in Utah, grew peas, native brome grass and wheat in eroded and non-eroded soils of the same type. They found that the plants in non-eroded soils produced more leaves, greater stem and leaf length and more dry matter than plants growing in eroded soils. The water requirement for plants on eroded soils was greater than for those on non-eroded soils. The conclusion was drawn that soil erosion is detrimental to plant growth because it brings about the two following conditions of soil impoverishment: (1) Lack of adequate soil moisture for the full development and seed production of the vegetation, and (2) lack of adequate plant nutrients in the soil for good growth. Seed germinated poorly on eroded soils and many of the seedlings died because of lack of moisture. The re-establishment of a good cover of vegetation on soils from which cover and top soils have been stripped is a difficult and slow process.

It is also known that density and character of herbaceous cover, which controls soil stability through its effect on rainfall run-off and soil erosion, is influenced by grazing. Chapline (1) cites investigations by McGinnies in Montana which showed that overgrazing a blue bunchgrass-sedge weed type of cover converted it into a rabbit brush-yellow brush weed type. The former type normally covered 60 to 80 percent of the soil surface and 2 acres of this cover would provide feed for one cow for one month. The latter type where the valuable grasses had given way to plants of low value covered only 20 to 40 percent of the ground surface and approximately 11 acres was required to furnish feed for one cow for one month.

Clements (2 - page 297) discusses the use of plants as indicators of overgrazing. He says:

> "The primary basis of overgrazing indicators lies in the fact that at any particular stage some species are eaten and others are not. Thus, at any time the degree of overgrazing can be determined from both sets of plants. The best method consists in using one set as positive indicators of excessive grazing, and the

others as a check upon these results; but in actual practice the most convenient indicators are naturally those that are not eaten. In any community such relict indicators owe their importance in the first place to the fact that the more palatable species are eaten down, thus rendering the uneaten ones more conspicuous. This quickly throws the advantage in competition to the side of the latter".

Methods of Study

Three characteristic soil-type areas representing areas of considerable extent, were studied. They are:

1. Shallow soils overlying deep deposits of marl or clay.

2. Shallow soils overlying quartzite or other base rock.

3. Shallow soils overlying pre-cambrian granitic base rock.

Within the soil-type areas paired plots of ground having the same slope and exposure and subject to similar climatic incluences were studied by the following methods:

1. The density and composition of herbaceous cover for the area related to the profile were determined by charting with a chartograph [2] or by ocular estimates of composition and density.

2. Measurements were taken of exposed profiles of soils and substrata which were found in road cuts, and ditches, or which were exposed by excavations dug to show the character of the profile. The profiles were sketched in order to show soil

[2] An adaptation of the pantograph used for charting of vegetation on meter square quadrats. The chartograph was devised and described by R. R. Hill. See Ecology 1:270-273, 1920.

depth, character of base rock or earth, and the contour of the present ground surface.

3. The relation of the present ground surface to that of the past as indicated by pedestal-shaped humps of soil under remaining vegetation, exposed roots, root collars of shrubs or half shrubs, and stone, gravel or rubble paving was sketched.

4. Photographs of profiles and vegetation on soil-type areas were taken.

The term, profile, is used to designate the vertical cross-section view of the various soil layers and substrata as exposed in a vertical cut. The top soil (sometimes called Horizon A) is the layer of soil which is usually more or less dark colored because of the presence of organic material. This layer contains more available plant nutrients than lower layers and most of the roots of herbaceous plants are found within it. The sub-soil or layer B (Horizon B) is the portion of weathered soil forming materials which have been changed by the addition of small amounts of organic matter and by materials leached from the top soil. The sub-soil usually has a heavier texture than top soil due to the accumulation of fine clay particles which have washed down from the upper layer.

Layer C (Horizon C) is the layer of soil forming materials which indicate the character of the parent material from which the soil is formed or may include earthy deposits upon which the soil forming materials lie.

Profiles which show only the location of the ground surface with respect to vegetation are termed ground surface profiles.

Studies

A. Studies of shallow soils overlying marl and clay deposits.

Two soil-type areas [3], designated as Areas Number 1 and Number 2, characterized by shallow deposits of stony, unconsolidated, conglomerate underlaid by deposits of marl or clay were studied. In each case the parent soil forming material was a product of water deposition, laid down during the tertiary period.

The shallow layer of conglomerate is characterized by rounded water-worn cobblestones. The deposits of clay and marl are very deep. Exposures of such deposits might be classed as "badlands". The weathering on their surfaces is characteristic. After a rainstorm the surface, as it dries out, shrinks and checks. The result is a granular surface with deep criss-cross checks. When sufficient rain again falls, the granular-like nodules are dissolved and washed away. The checking process is again repeated when the ground dries out.

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[3] The term soil-type area is used to designate areas which have a characteristic layered arrangement of soil, soil forming materials and substrata.

Soil-type Area 1

The area is located on the Espanola-Tierra Amarilla Highway, 10 miles northwest of Abiquiu and one half mile west of the present channel of the Chama River, a large tributary of the Rio Grande, in a wide basin between Mesa Vieja and the Jemez Mountains in northern New Mexico. The vegetation is savanna woodland in character and herbaceous vegetation is similar to that of semidesert grasslands of high plains. The elevation is approximately 6200 feet above sea level. The shallow upper layer consists of organic soil, sand, and water-worn pebbles varying in diameter from 2 to 8 inches. This caps a deep deposit of dark purplish-red marly clay. Two plots [4] of ground on an east facing exposure were studied.

Comparison of vegetation:

Density and proportionate composition of vegetation on two paired plots was determined by ocular estimate and by charting. Care was used to locate the two plots on ground of about the same percent of slope and about equidistant from the top of the slope. Plot A was located on a portion of the slope that was easily accessible to livestock and on which

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[4] The term, plot, as used in this report refers to a small area of ground varying in size from 1 meter square to 50 feet square on which measurements or estimates of density and composition of vegetation were made.

herbaceous vegetation had recently been grazed very close to the ground. Plot B was located above a deep road cut and was not easily accessible to stock and the forage grasses were not grazed so closely. The contrast in vegetation is shown in the following tabulation:

Vegetation on Plot A

Slope 20% -- area 50 feet square

Proportionate composition

Species	Percent	
Hilaria jamesii (galleta grass)	15	
Bouteloua gracilis (blue grama)	10	
Bouteloua eriopoda (black grama)	10	
Muhlenbergia gracillima (ring grass)	40	
Sporobolus cryptandrus (dropseed)	2	
Aristida longiseta (three-awn)	3	
Total grasses: ---------------		80
Gutierrezia sarothrae (snakeweed)	2	
Salsola pestifer (Russian thistle)	2	
Total weeds: -----------------		4
Juniperus monosperma (one seed juniper)	16	
Total trees: -----------------		16
Total: ------------------		100%
Density --------------------------	15%	

Vegetation on Plot B

Slope 18% -- area 50 feet square

Proportionate composition

Species	Percent	
Hilaria jamesii (galleta grass)	45	
Bouteloua gracilis (blue grama)	25	
Bouteloua eriopoda (black grama)	10	
Muhlenbergia gracillima (ring grass)	5	
Aristida longiseta (three-awn)	2	
Total grasses: ---------------		87
Salsola pestifer (Russian thistle)	2	
Total weeds: -----------------		2
Juniperus monosperma (one seed juniper)	11	
Total trees: -----------------		11
Total: ------------------		100%

Density ----------------------------35%

It will be noted that although weeds have not replaced the grasses on Plot A to any appreciable extent the large percentage of ring grass, a recognized indicator of over-grazing in this particular region (9) indicates that over-grazing by livestock is the cause of the low density of vegetation on Plot A. It will also be noted that the grass density on Plot B is more than twice that of Plot A.

Comparison of profiles:

Two profiles were sketched to determine character of ground surface on a portion of each plot in relation to vegetation. The profile of Plot A with chart showing location of grass tufts on a small area shows that top soil has been eroded to a depth of 2 to 7 centimeters (Figure 7). The low density of vegetation has not prevented the washing away of the top soil even though the ground surface is partially covered by cobblestones. In places the top soil has been entirely eroded away exposing the sub-soil (Figure 5).

On Area B the grasses and imbedded cobblestones form a good protective cover and there is no noticeable erosion of soil (Figure 5). A profile along the edge of B, as exposed on the face of the deep road cut, shows the upper 18 inches has been altered by the gradual addition of organic material derived from the grass cover. This is evidenced by a darker color and a change in texture from a loose sand to a mellow, friable, sandy loam. The top soil holds together well, indicating that it is more resistant to erosion than the lower layer of loose sand and round water-worn cobblestones. The ease with which this material may be dislodged from the face of the cut shows it to be very unstable. The deposit of marly clay underneath the two upper layers is estimated to be thirty feet deep (Figures 4 and 6). In places, erosion has stripped away the upper soil layers exposing the marly clay deposit and a few miles north of Abiquiu there are extensive exposures of similar deposits on which there is practically no vegetation (Figure 4). This would indicate

A

Stratification of soil, sand, cobblestones and underlying marly clay bed shown in a road cut on Tierra Amarilla-Espanola Highway 10 miles north of Abiquiu. (Photo by U. S. Forest Service.)

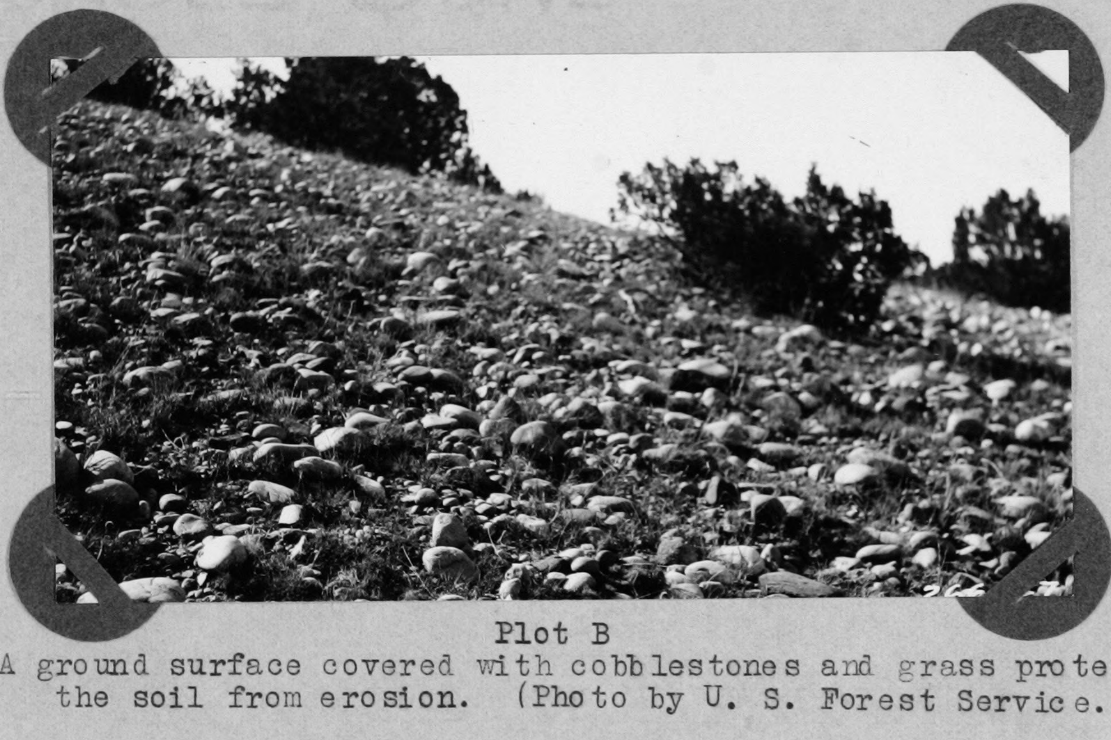
B

Exposures of marl-like clays in the lower Chama Basin north of Abiquiu, New Mexico. (Photo by U. S. Forest Service.)

Figure 4.

Plot A

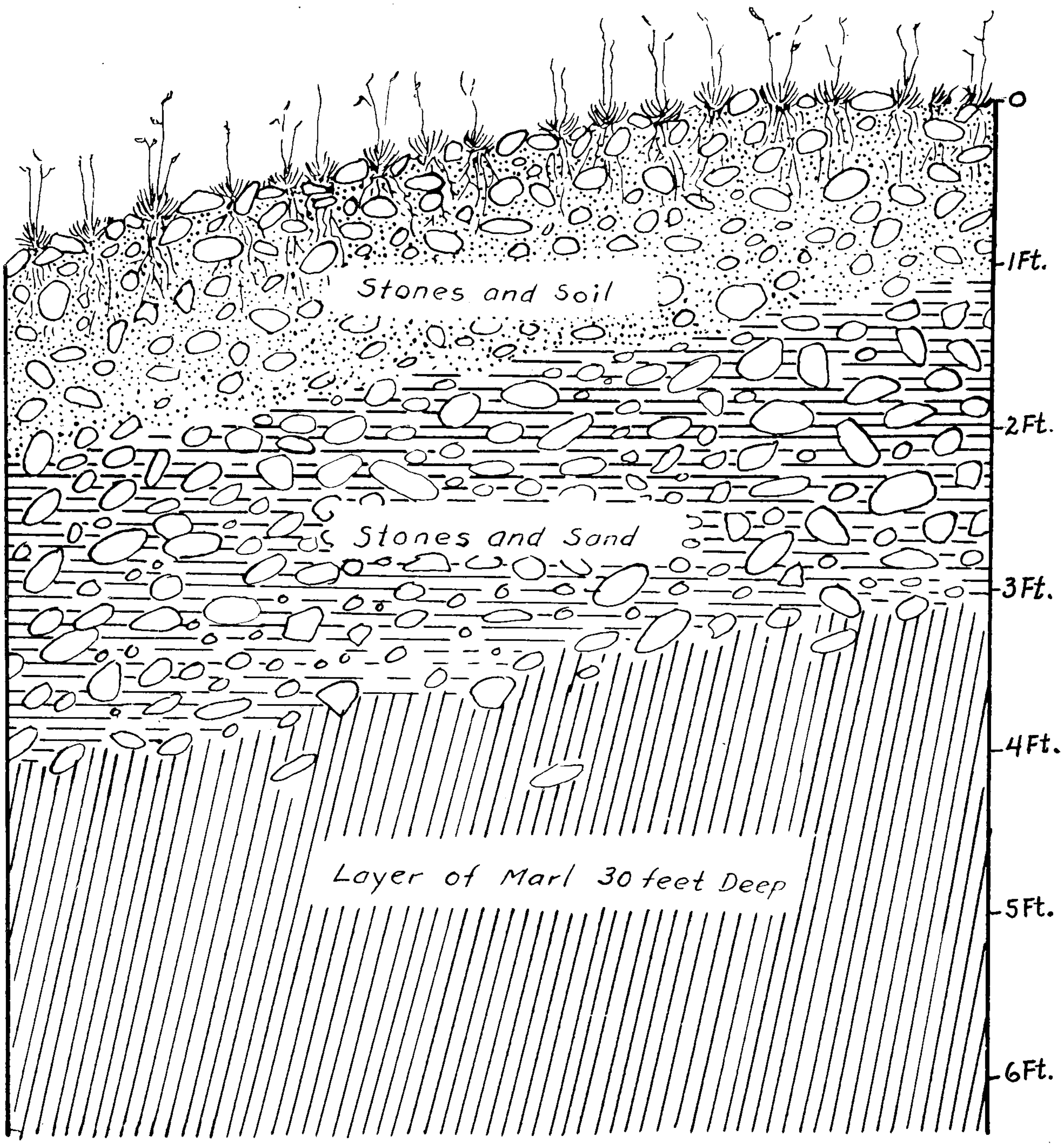
The grass cover has been deteriorated. Erosion has removed most of the upper soil layer. Breakdown of exposed loose sand is rapid despite the partial covering of cobblestones. (Photo by U. S. Forest Service.)



Plot B

A ground surface covered with cobblestones and grass protects the soil from erosion. (Photo by U. S. Forest Service.)

Figure 5.



Face of Cut on Chama - Espanola Road 10 Miles Northwest of Abiquiu, New Mexico, Showing Shallow Depth of Soil Overlying Material Susceptible to erosion

Figure 6

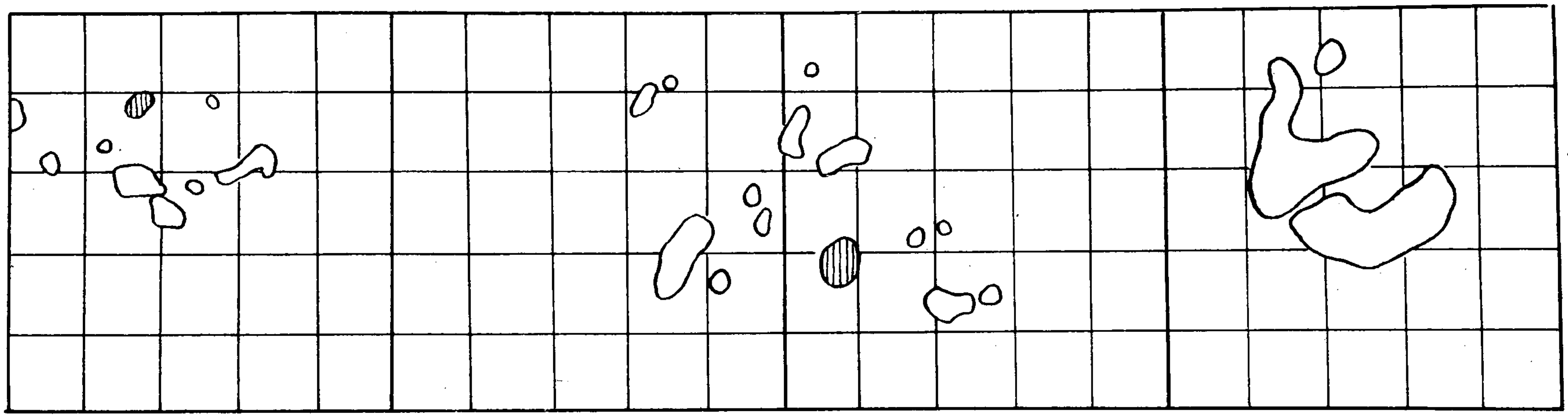
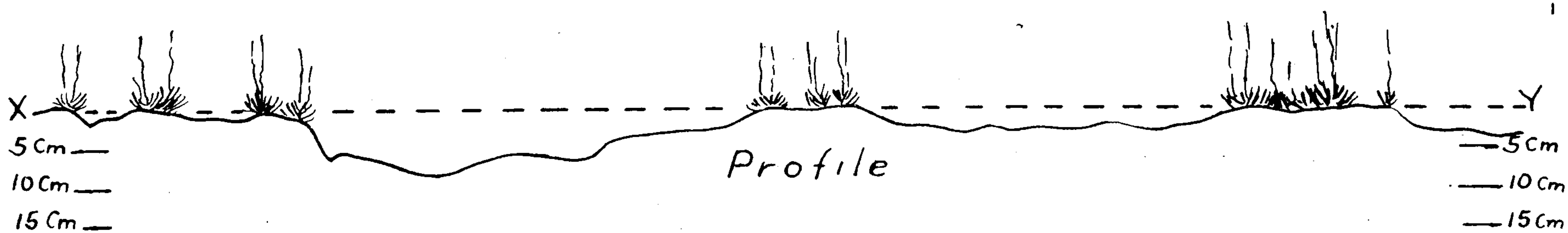


Chart of Vegetation on Four Square Meters



Profile

Ground Surface Profile and Grass Cover on 20 % Slope S.E. Exposure
10 miles Northwest of Abiquiu New Mexico

= Dead Galleta Grass
= Living Galleta Grass

- - - - Ground Level of Recent Past
Present Ground Level

Figure 7

that after top soils have been eroded and marly deposits have been exposed natural revegetation would take place very slowly. The texture of the material is very heavy, its surface is unstable and the percentage of moisture entering the material is low because of the high percentage of run-off from bare spaces.

To summarize briefly: The significant facts brought out by the comparison of Plots A and B are these.

(1.) The cover of vegetation on Area A is of low density and the proportionate composition of plant species forming that cover indicates that deterioration of cover is due to overgrazing.

(2.) Top soil on Area A shows development of characteristic soil features in that soil has organic matter, is dark colored and friable in texture. However, this top soil has been eroded in places to an average depth of 5 centimeters.

(3.) Area B has a cover of vegetation that approaches in density and proportionate composition the climax vegetation of semidesert grasslands in the region studies.

(4.) Top soil on Area B also shows characteristic development of soil features but is not eroded to a noticeable degree.

(5.) The profile of A (Figures 5 and 7) shows that even the cover formed by a combination of grass and cobblestones can be broken down by overuse. Where the top soil is gone there is evidence of soil erosion in the loose sand and cobblestone layer or the deeper deposit of marly clay. The profile of B (Figure 6) reveals a shallow layer of top soil which overlies the other deposits protected by a good cover of climax grasses and imbedded cobblestones, an excellent cover combination.

Soil-type area number 2 is located about one and one half miles northeast of Cuba, New Mexico, at an elevation of about 7,000 feet above sea level. It is similar to area number 1 in that herbaceous vegetation is of the semidesert grassland type. The area has a southwest exposure and a slope of about 15 percent. Although the soil layers are of the same general character the topsoils where present are much shallower.

Comparison of vegetation:

Plot A is entirely bare of vegetation (Figure 9). Plot B, 50 feet square in area, has the following cover:

Proportionate composition

Species	Percent	
Bouteloua gracilis (blue grama)	35	
Hilaria jamesii (galleta)	25	
Aristida Sp. (three-awn)	10	
Total grasses:		70
Salsola pestifer (Russian thistle)	6	
Gutierrezia sarothrae (snakeweed)	4	
Total weeds:		10
Artemisia Sp. (low sagebrush)	12	
Chrysothamnus (rabbitbrush)	8	
Total shrubs:		20
Total:		100%
Density	20%	

Grazing use of the portion of slope characterized by the bare exposures of sub-soils has been most intense in the past as this area lies in a passway through which stock have trailed to reach areas beyond the ridge. Portions of old stock trails are still visible and they give a clue to the reason for deterioration of vegetation and soil.

The vegetation on Plot B even shows the effect of intense grazing use in deteriorated density and changed composition (Figure 9).

Comparison of profiles:

On Plot A there is no top-soil layer. Near the top of the slope exposed tree roots give an idea as to the depth of the former surface covering. Stones in the small drainage (Figure 9) and those which have ravelled down to the base of the slope are proof that the original layer, like the upper layer of B, was stony.

The profile on Plot B shows the layer of material which is exposed on A to be covered by a layer of top soil. Samples from the lower layer of clay on B and the clay exposed at surface on A were carefully compared and found to be similar in texture, color, and in capacity to shrink when dried out. The first 6 inches of the soil layer on B is stony (Figure 8); the next 12 inches is made up of dark colored soil which gradually grades into the dark clay below. The upper portion of this 12 inch layer contains considerable organic matter and shows the development of soil features.

A significant thing about the exposed material at A is the manner in which it checks on drying after being wet up by rainfall. It develops a hard granular surface when dry. When rainwater falls on the sloping surface the top coating is dissolved and washed off. As the surface dries it again checks into tiny squares and these segments shrink, forming another granular layer. A few days after this record was taken, the writer observed during the course of a hard rainstorm in which about 1 inch of rain fell the removal of the entire weathered layer which was more than an eighth of an inch in thickness from a similar exposure of clay. This would indicate that erosion on such exposures is great.

The lowering of the ground surface between grass tufts and the accumulation of stones on Plot B indicates a removal of soil by erosion, although it is apparent from Figure 9 that erosion is much less there than on Plot A.

The significant facts are that Plot A supports no vegetation, in fact it is hard to see how any revegetation could take place naturally because of the unstable character of the surface while the topsoil at B supports a cover of vegetation and an increase in density could be expected if the area were protected from heavy grazing use.

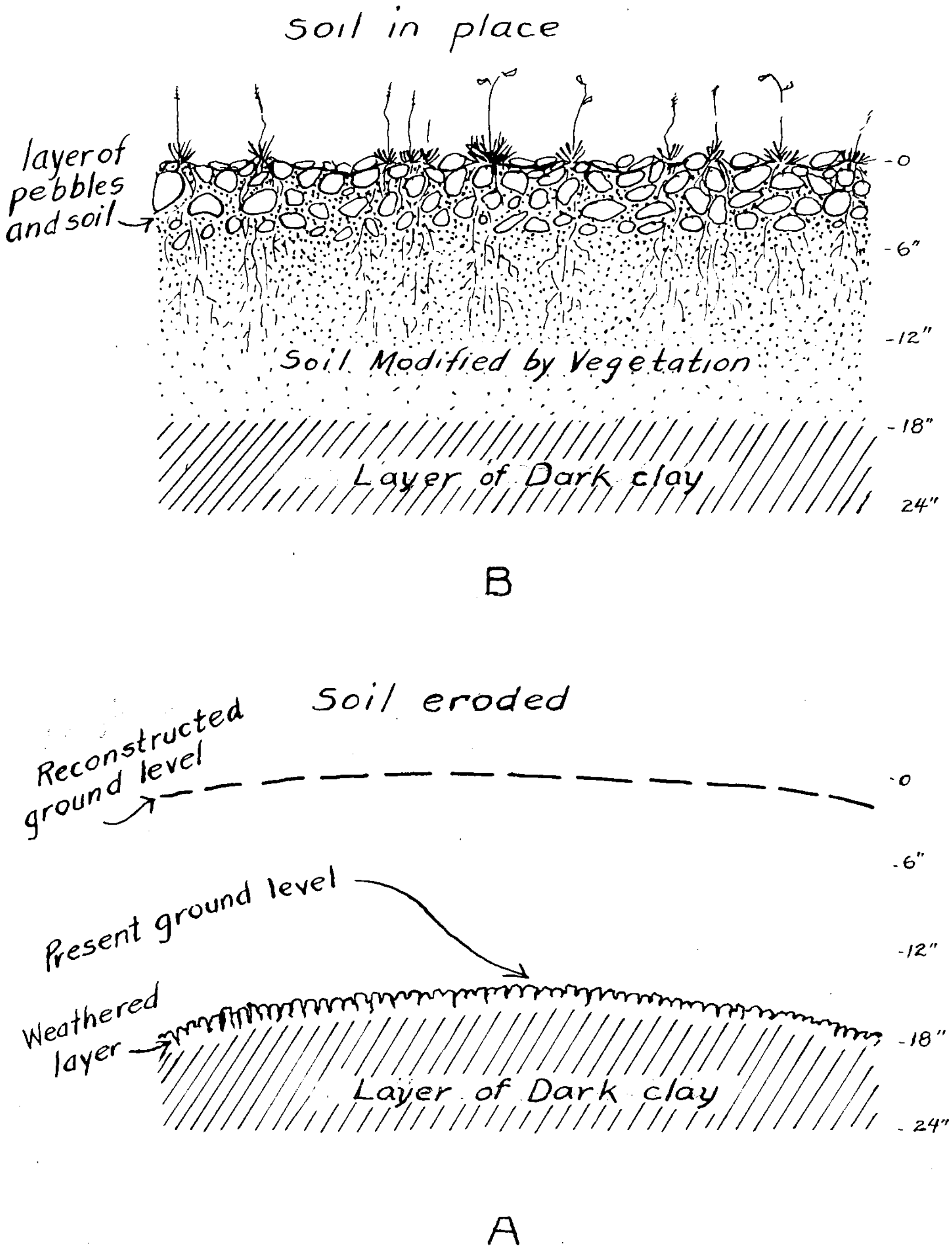

Soil in place
layer of pebbles and soil
-0
-6"
-12"
Soil Modified by Vegetation
-18"
Layer of Dark clay
24"
B
Soil eroded
Reconstructed ground level
-0
-6"
Present ground level
-12"
Weathered layer
-18"
Layer of Dark clay
-24"
A

Figure 8

Slope northeast of Cuba, New Mexico

At A erosion has stripped surface soil down to clay sub-soil. The rock litter in drainage gullies and exposed roots of trees in background are evidence of the former ground level. The clay exposed at A is encountered at a depth of 18 inches at B. At B the slope still retains a surface cover of upper horizon soil and some herbaceous vegetation. (Photo by U. S. Forest Service.)

Figure 9.

B. Studies of shallow soils overlying quartzite or other base rock

The soil-type areas characterized by shallow soils over solid rock are located in regions where climate is favorable to the production of an excellent grass cover on undisturbed soils. When bed rock is exposed conditions are obviously not favorable for re-establishment of vegetation. Two areas in Arizona were chosen as representative of this soil-type. They are designated as Sierra Ancha Bench Area and Helvetia Slope Area.

Sierra Ancha Bench Area

This area is located on a high bench formed by the westward extension of horizontal beds of quartzite in the Sierra Anchas. The beds dip to the east, giving the bench a distinct eastward slope. The elevation ranges from 4000 to 4500 feet above sea level. Soils range in depth from 8 inches to 4 feet or more and are quite heavy in texture.

Profiles were made to determine depth of soil and relation of surface profile to vegetation on three plot areas which are designated as 1, 2 and 3. Number 3 was located where the soil is three to four feet deep and where soil has been gullied to bed rock in several places. This area has been heavily grazed.

Number 2 was located where soil was shallow, about 6 inches in depth, and vegetation has been heavily grazed.

Number 1 was located on a rocky promontory of the rim of the quartzite bench where the soil is about 8 inches deep. The promontory, known as the "Natural Corral", is partially protected from grazing as it is rather inaccessible. It has, however, been used to some degree.

Comparison of vegetation and soil:

The relation between herbaceous cover and soil stability is shown in Table 1 and Figure 11. Soil erosion is retarded very little by the snakeweed cover on plot area 3. Between the widely spaced plants miniature gullies are found. In places the soil has been completely removed and bedrock is exposed. Run-off from such areas is destructively rapid. Flood plains of main drainage lines below the bench are being cut away by repeated floods which originate in part on the bench area. The shallow depth of soil on this formation is shown in the three profiles in Figure 11. New gullies have been formed on portions of the bench area since I first observed it in 1926. The rapidity of such erosion is in itself sufficient evidence that present erosion is abnormally great. Profile 2 shows an accumulation of rock fragments at the surface due to excessive sheet erosion. That the 30 percent cover of vegetation on plot area combined with a covering of rock fragments is effective in holding the shallow layer of top soil in place is indicated by the lack of miniature gullies, lack of excessive amount of rock on surface and the absence of soil humps under grass tufts. Uniform ground level and friable soil covered by plant growth or plant litter shows no evidence of soil washing or erosion. The profiles bring out the following facts in regard to this soil-type area, namely:

1. Soils are fairly shallow and are underlain by dense, almost horizontal layers of quartzite.

2. In places fully open to grazing, vegetation has deteriorated until weeds, chiefly snakeweed, from 75 to 90 percent of the cover which is low in density. Such a condition is in itself evidence of overgrazing.

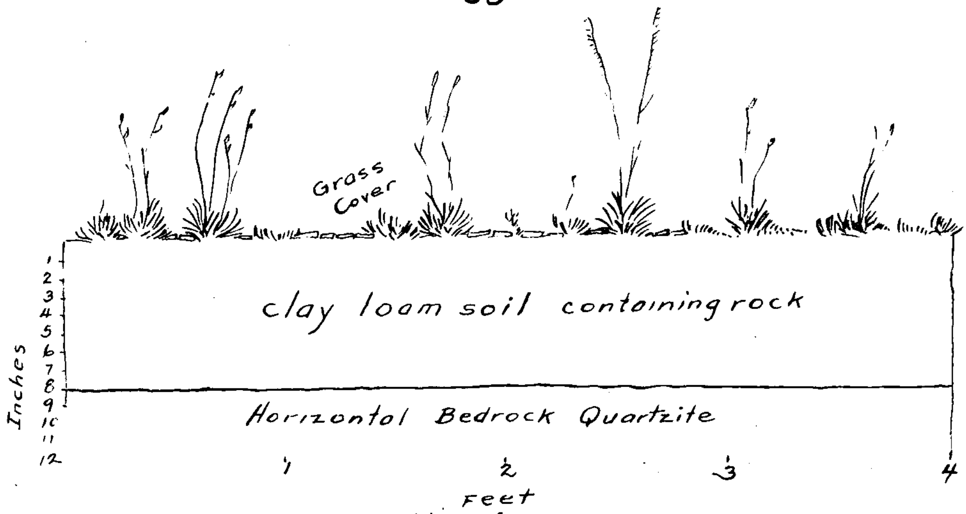
3. On the area partially protected from grazing vegetation approaches that of the climax vegetation with grasses forming 65 percent of the cover.

4. The existence of the soil layer over the horizontal quartzite is evidence of the existence of a protective cover of vegetation over a long period in the past for formation of even a shallow layer of top soil with organic matter incorporated in it requires centuries of time under southwestern conditions.

Table No. I.

Vegetation and Soil Stability
Plot Areas on Sierra Ancha Bench

Area	Plant Species	Composition	Density	State of Soil Stability
Plot area 3	Melica Sp. Aristida arizonica " purpurea	Grasses 5%	10% of a complete ground cover.	Paving of rock fragments broken down. Soil completely removed to bedrock in places.
	Gutierrezia sarothrae Ayenia Sp. Helianthus Sp. Cassia covesii	Weeds 90%		
	Baccharis pteronoides Opuntia phaeocantha	Shrubs 5%		
Plot area 2	Bouteloua curtipendula " hirsuta Hilaria belangeri	Grasses 10%	15% of a complete ground cover.	Soil subject to abnormal sheet erosion leaving the surface heavily paved with quartzite fragments.
	Gutierrezia sarothrae Eriogonum wrightii Chamaesyce Sp.	Weeds 75%		
	Agave lechequilla Opuntia discata Quercus turbinella	Browse 15%		
Plot area 1	Bouteloua curtipendula Lycurus phleoides Bouteloua hirsuta Aristida divaricata Muhlenbergia rigens	Grasses 65%	30% of a complete ground cover.	Soil in a stable condition. Portion of surface not covered by vegetation is covered by platy fragments of quartzite. No noticeable erosion.
	Eriogonum wrightii Ayenia Sp. Other weeds	Weeds 20%		
	Dasylirion wheeleri Fouqueria splendens Quercus turbinella Opuntia discata Other shrubs	Shrubs 15%		



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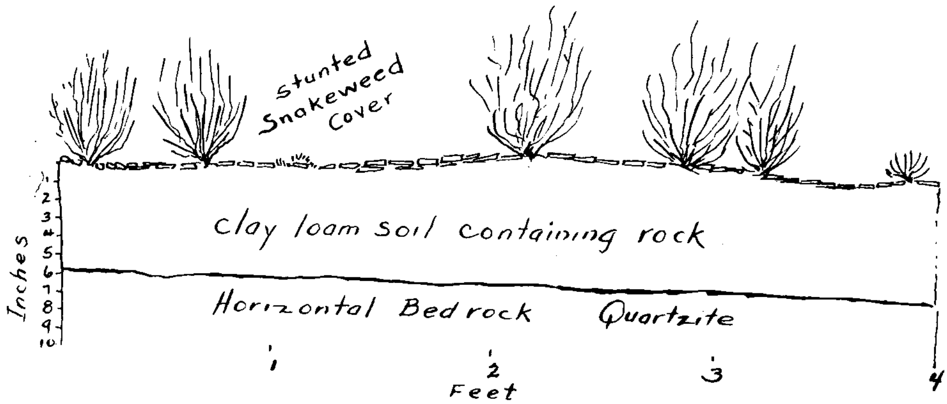

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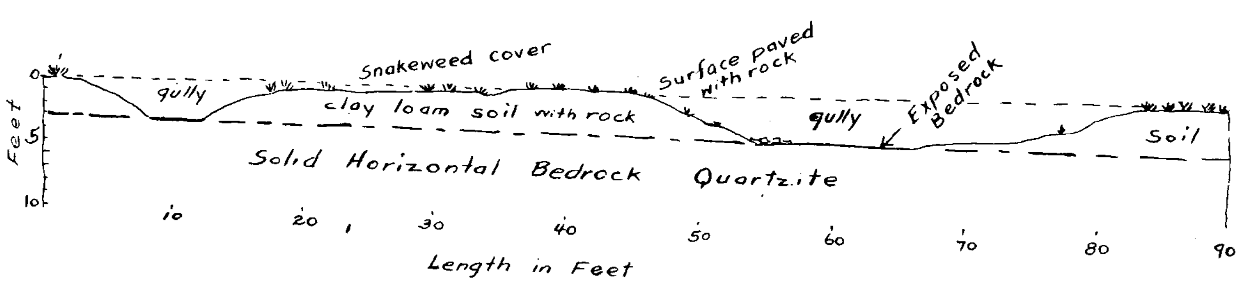

No. 3

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Character of Cover Soil depth Underlying Rock

Figure 10.

Deteriorated cover (snakeweed), excessive soil erosion and gullying to bedrock on quartzite bench as in number 3, figure 10. (Photo by U. S. Forest Service.)

Figure 11.

Helvetia Area

Near the old mining camp of Helvetia in the northwest foothills of the Santa Rita Mountains, chart measurements of cover density and soil stability were made on two meter square quadrats in order to determine conditions under which topsoils erode and conditions under which they do not erode.

The underlying rock of the immediate region is coarse granite. The uneven profile of the underlying mass accounts for variation in depth of soil. This depth may range from several feet in pockets to shallow layers six inches deep on the ridges. The soil deposits in the small valleys are deeper and more uniform.

The two quadrats are quite similar as to underlying formation and slope. The cover density varies from 5% of a complete cover on the quadrat where cover is deteriorated and soils have been excessively eroded to 42% of a complete cover on the quadrat supporting a conserved cover with a minimum of soil disturbance.

From the chart of quadrat A in figure 12 it is evident that the cover of vegetation is not thick enough to hold up soil once set in motion, although the soil actually covered by vegetation is held in place by the grass roots which form a network, binding the soil mass together. If small clumps, such as these, can hold pedestal-like humps of soil, the protective influence of the cover shown in Figure 13 must be very effective. The removal of soil by erosion between the clumps is visible evidence of accelerated erosion due to the accumulation and concentration of run-off.

That the 42% cover on Quadrat B is quite effective in maintaining soil stability is shown by the profile below the chart of vegetation in Figure 12. There is a slight movement of soil on the bare spaces which constitute slightly more than one half of the surface area, but the arrangement of grass tufts is such that this movement is checked by litter which collects between closely spaced tufts. The effect is to form minute terraces where the cover is most dense. The location of terraces in respect to density of vegetation is illustrated on the chart.

An effective grass cover prevents soil erosion in two ways, namely:

1. It actually protects the soil from the wear and tear of erosive forces.

2. It prevents the accumulation and concentration of surface run-off in large volume before it reaches a natural drainage channel.

Grass cover (including litter) protects the soil from the beat of rain and forms an absorptive mantle which takes up water rapidly. This prevents the accumulation of the large volume of water which is responsible for the destructive and accelerated erosion which occurs when hard rains fall on bare soil.

For purpose of comparative study Table II, detailing in brief the character of cover and soil on the two quadrats has been compiled.

The area represented by quadrat B containing 42% cover has been used conservatively since 1911, at which time the Santa Rita Experimental Range was fenced. The area represented by the quadrat containing 5% cover had been subjected to extremely heavy use prior to 1924 and from 1924 to 1932 continued to suffer from overuse resulting in the present deteriorated condition.

The difference in cover cannot be attributed to climate or other physical factors. It is due to differences in cover as affected by two systems of grazing use, differing as to intensity, the history of which is fairly well known. On one area the grass cover has been broken down, reduced in density and almost eliminated by persistent and continued overuse by grazing animals. On the other, under conservative grazing use which leaves sufficient volume of grass stalks and leaves to provide for continued regeneration of

Table II. Comparison of two conditions of plant cover and soil stability

Location and description of area representing	Underlying rock formation	Soil depth	Soil description	Character of cover	Surface control	Conditions favorable or unfavorable to maintenance of cover
Disturbed soil condition Gentle slope West exposure Heavily overgrazed for years by cattle, horses and burros	Granite	8 to 12 inches	Friable loam soil confined to pedestals under grass tufts - elsewhere eroded down to heavy sub-soils.	5% of a complete ground cover of small, wide spaced tufts of slender grama.	Extensive movement of soil between scattered grass tufts. Soil once in motion moves entirely out to lower levels. Loss of soil is evidenced by small gullies and lowered levels between tufts.	Conditions are favorable for rapid run-off. There is no litter and vegetation is not dense enough to hold up water. Silt carried in suspension seals up pore spaces. Less water enters soil.
Stable soil condition Gentle slope Northwest exposure Conservatively grazed	Granite	6 to 10 inches	Dark brown, friable loam on surface shading into a brown, heavy clay subsoil. Soil favors maintenance of vegetation.	42% of a complete ground cover composed of tufts of slender and hairy grama. Bare spaces are surrounded by closely spaced tufts.	Slight movement of soil in bare spaces causes miniature terraces to form where grass clumps close in. Litter forms miniature check dams.	Conditions are favorable for absorption of rainfall. The water held up by riffles of litter and closely spaced grass tufts has more time to penetrate.

the stand, the cover has been maintained in a very effective state.

Table 2 illustrates the changes which can take place by the overuse of grass cover and brings out the significant differences between the two quadrates.

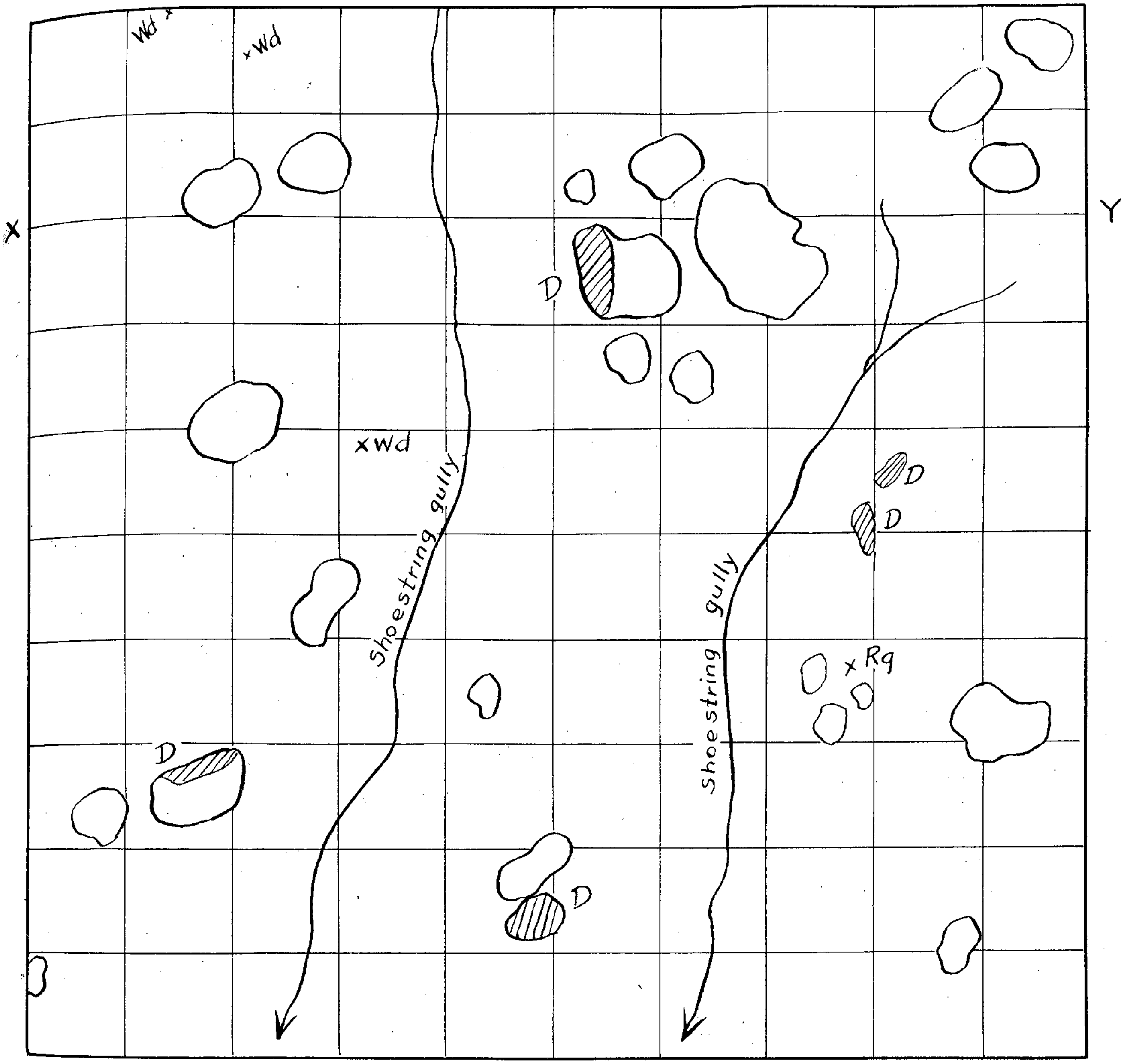
C. Studies of granite soils overlying Precambrian granite base rock:

The granite soils are located on the Salt River Watershed in Arizona, the particular areas where measurements were taken, near the summit on the Globe-Roosevelt Road, at an elevation of about 4000 feet above sea level.

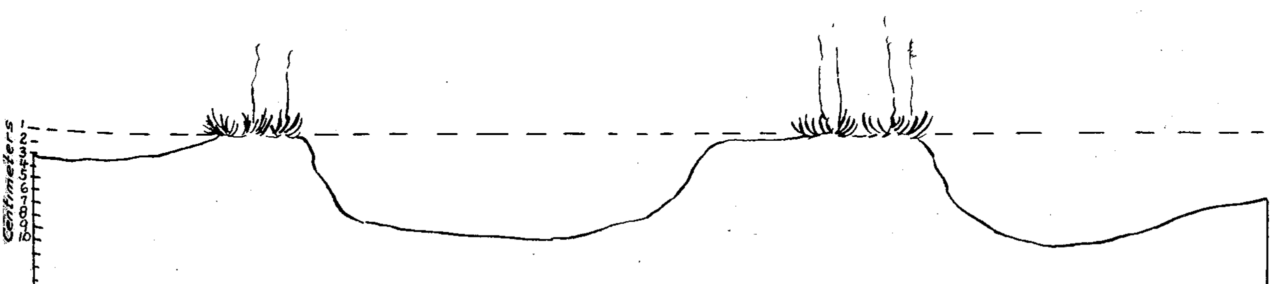
Soil erosion has already reached an advanced stage. Deep gullies on steep slopes, wide rubble filled washes and rubble paved slopes are indicative of accelerated erosion of soils and soil forming materials. The particular area studied has a south exposure and a slope averaging about 30%.

Vegetation:

Open-crowned shrubs such as *Acacia greggii*, *Acacia constricta*, *Lycium pallidum*, *Condalia lysioides* var. *canescens* and half shrubs such as *Krameria glandulosa*, *Krameria grayi*, *Calliandra eriophylla*, and *Eriogonum wrightii* constitute the greater portion of the cover. Grasses such as *Aristida arizonica*, *Bouteloua chondrosioides* and *Bouteloua curtipendula* form a very low proportion of the total cover. Density of



Meter Square



Bisect at XY

Grass tufts Slender grama
Dead Grass
Minature gullies --- Ground level of recent past

Figure 12

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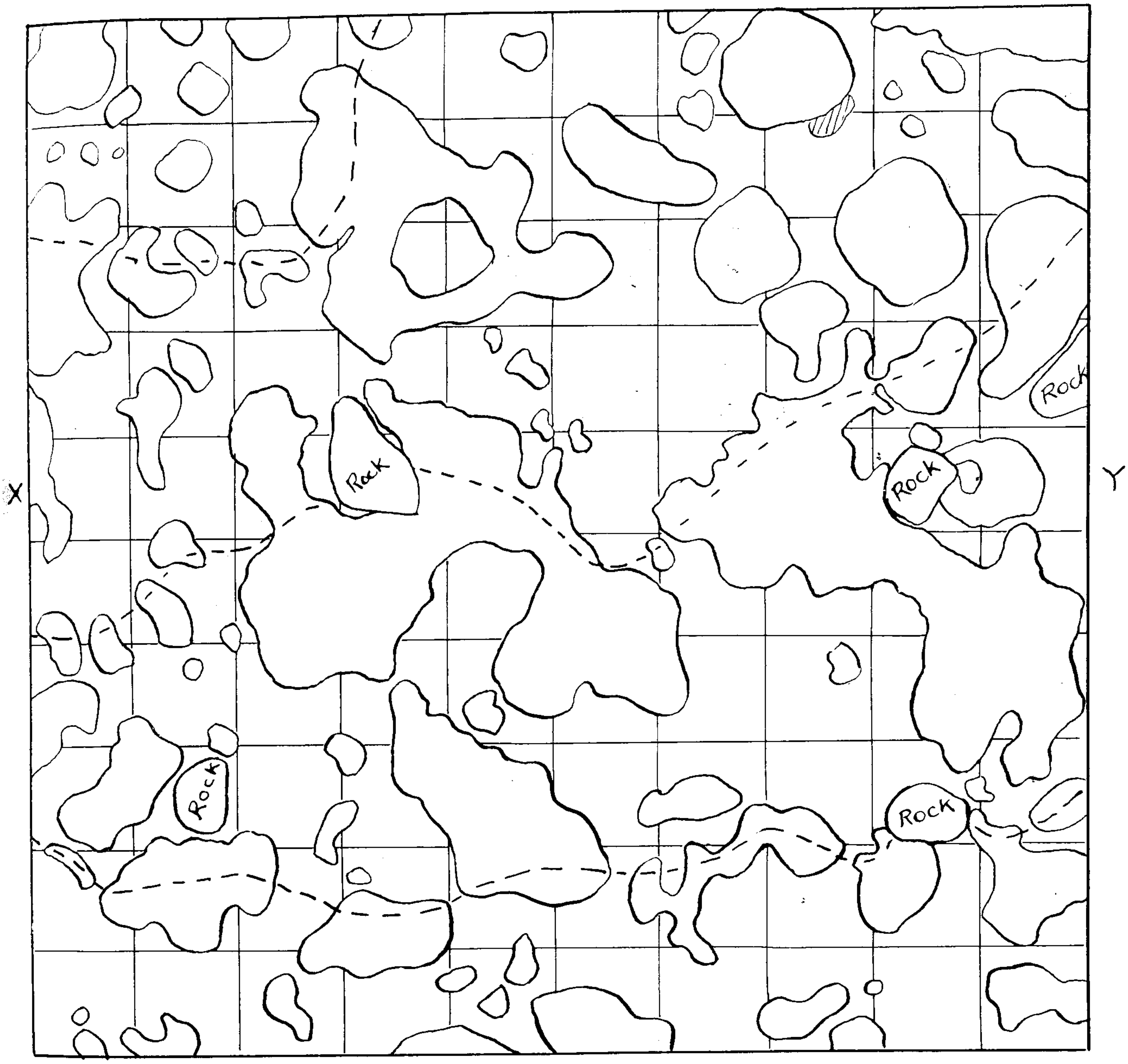
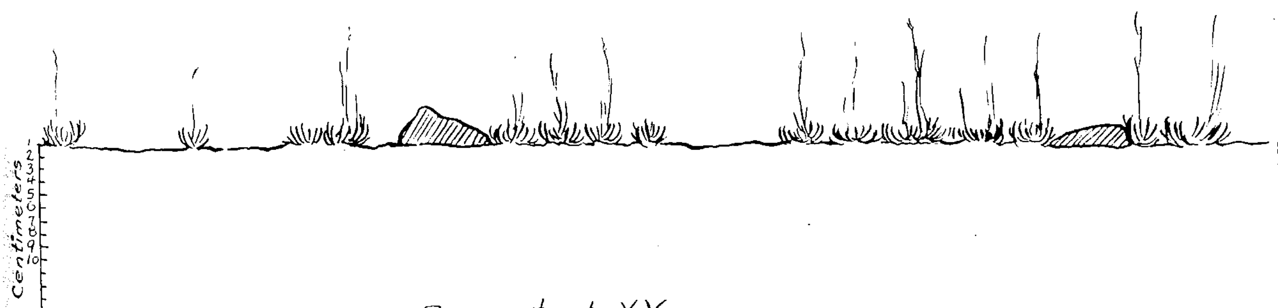


Meter Square



Bisect at XY

Grass tufts   Slender grama - Hairy grama

Dead Grass

--- Outline of small terraces where soil and litter is held

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Figure 13

vegetation varies from 10 to 25% of a complete ground cover. The ground cover at the top of the slope, where the pitch is steep, averages less than 10 percent. Ground not occupied by shrubs is practically bare.

The percent of slope decreases on the lower portion of the slope and grasses occupy a portion of the space between shrubs. At the foot of the slope there is a large fan built up by material which has been eroded from the upper slope and this is largely occupied by _Acacias_ and _Eriogonum wrightii_.

Soil:

Examination of the steep portion of the slope revealed a shallow layer of soil about 3 to 6 inches overlying granite rock. The shallow soil was covered by a layer of granite rubble (rubble grains are about one fourth inch in diameter). The more gentle slopes had a deeper layer of soil, 20 inches deep in places.

Soil erosion:

It is evident from the fan at the base of the slope that erosion on the area has been very active. Furthermore the bisect (Figure 14) through the fan at the base of a small drainage area shows the material to have been deposited in recent time. The deposit is not due to a shift in the course of a gully as the fans extend across the entire base of the slope. A living shrub buried to a depth of 2-1/2 feet is evidence of the rapidity of deposition. A ring count shows the buried acacia to be approximately 30 years old. It is apparent that the material deposited at the base of the slope has been eroded from the upper slope within this approximate period.

The material deposited above the original level of the root collar of the acacia has a stratification differing from that of the soil below the root collar. The upper material is composed of alternating layers of fine and coarse material characteristic of deposits built up during a period of greatly accelerated erosion. The soil below has a more uniform and finer texture. The soil features indicate a long period of soil development before accelerated erosion set in.

The condition of the original soil profile (Figure 14) presupposes a stable condition for the slopes above, necessarily indicating that the soil and soil-forming material (which was at that time covering the slopes but now makes up the big fill at the base of the slope) had a cover sufficient to prevent accelerated erosion. From ecological studies made in the region it is evident that grass was the effective cover.

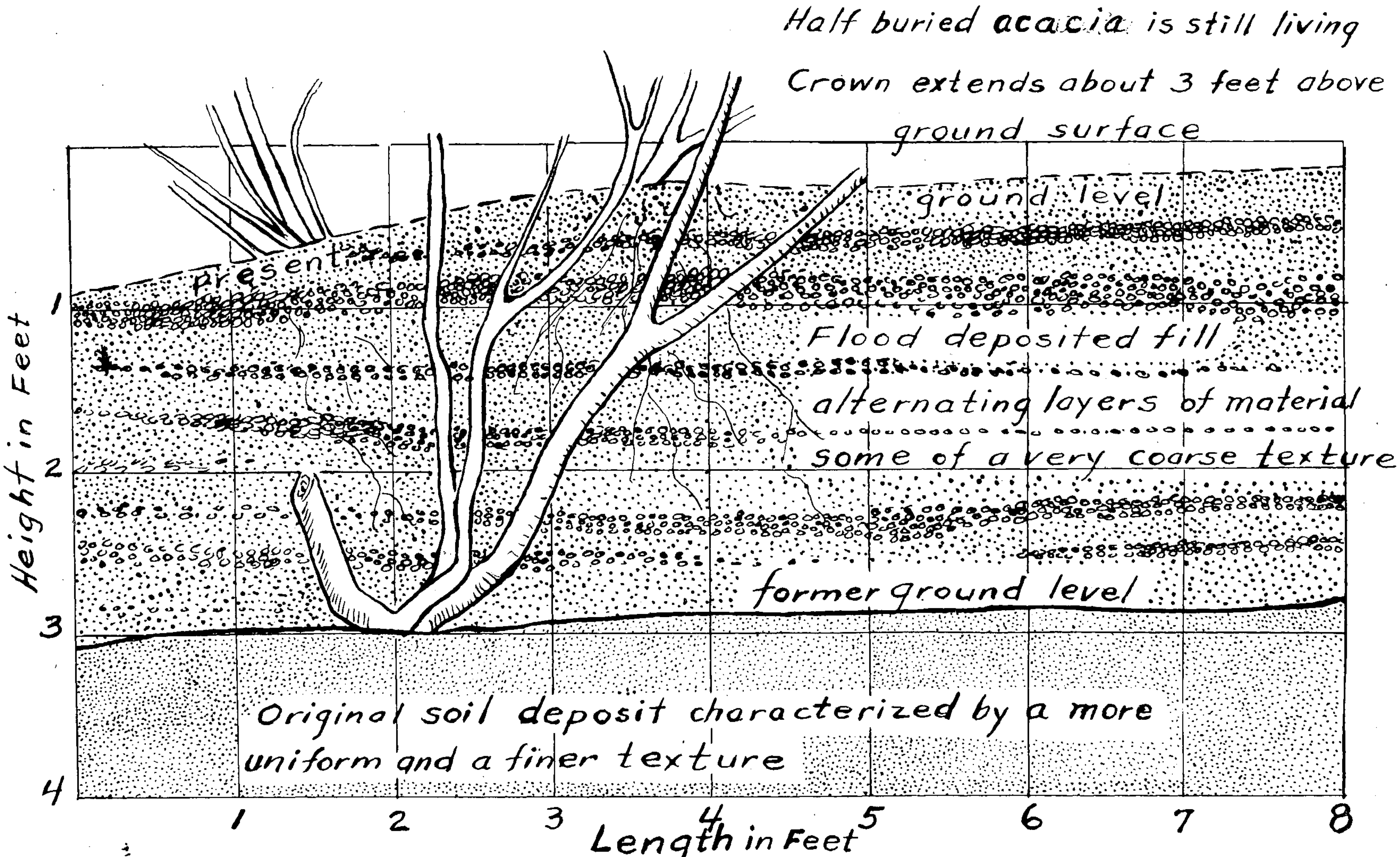

Fig. 14 Bisect through flood deposited fill at base of drainage area of ½ acre in granitic soils

Soil erosion on the small watershed above this fan was measured by the Parker Creek Experiment Station (Forest Service). Run-off and eroded material was collected and measured in concrete ditches at the base of the slope.

Eroded material from this area of 25,876 sq. ft., for the period July 1, 1931 to October 1, 1933, amounted to 441 cu. ft. which is equivalent to a surface removal on the small watershed of .204 inches within the brief period of two years and four months.

Profile measurements from a series of stations to determine change in surface due to cutting and filling by erosive processes were made on the slope which includes the small watershed from which eroded material was measured. Vertical measurements from a horizontal tape stretched between two pipes set in concrete were taken at intervals of 2 tenths of an inch each year. During the period December, 1930 to December, 1932 the profile measurements show a loss of soil averaging .216 inches.

Surface removal approximately .1 of an inch of soil to the year is equivalent to a removal of 1 inch in 10 years or 10 inches in 100 years. This rate of soil removal is far in excess of the rate of soil formation.

Relation of soil-type areas to other areas in Arizona and New Mexico

The soil-type areas studied are not large in area. They are, however, quite typical of larger areas within Arizona and New Mexico.

Whether the extensive deposits of marls, silts and clays exposed in the Santa Fe Marl formation and in similar geologic formations of Arizona and New Mexico were ever covered by a layer of top soil and vegetation is a matter for conjecture and beyond the scope of this study. However, the soil-type areas studied show quite definitely that clays and marls similar to those found on badland exposures do have a covering of top soil and vegetation and that when this covering of soil and vegetation is broken down the exposed marls and clays resemble older "badland" exposures.

Areas of bench and mesa lands on which soils are more or less shallow and which have underlying strata of limestone, sandstone, quartzite or basalt are quite extensive. The soils are a resource which can be removed by accelerated erosion within a relatively short period of time. Run-off from bare rock areas exerts destructive influences on alluvial valleys below mesas and bench lands.

Conclusions

I. Measurements of soil surface profiles show that soil erosion has removed a portion of the top soil from certain soil-type areas in Arizona and New Mexico. The extent of soil removal is shown by amount of rock or rubble paving, tufts of vegetation on pedestal-like humps of top soil, exposed root crowns of half shrubs and shrubs, miniature gullies and lowered ground levels between mounds of soil in place beneath shrubs or other vegetation.

II. The rate of soil erosion on the areas studied when compared with rate of soil formation is very great and far exceeds the normal geologic erosion. The rate of removal on Precambrian granitic soils deteriorated of vegetation is such that areas covered with shallow soils will be entirely bared of soil within the next 100 years if the present rate is maintained.

III. Extreme loss of top soil is associated with low densities of plant cover. This cover as a rule is composed of plants of low forage value, which are of a sub-climax or lower successional stage. Soil stability is associated with high densities of cover and the plants are usually climax species of high forage value. This is well exemplified by the vegetation on the Sierra Bench Area. An almost pure snakeweed (Gutierrezia Sarothrae) cover of low density is found on areas where soil erosion is far advanced. A mixed grass cover of high density is found on areas where the soil is not eroded.

Low densities of vegetation and plant associations of low value on the areas studied were found to be due to overgrazing. High densities of vegetation and associations of high value were found on areas grazed moderately.

IV. Soil erosion on the soil-type areas studied merits consideration from four standpoints:

1. The layer of productive top soil is very shallow. Erosion may remove, within the lifetime of man, the entire A horizon layer built up by natural processes through centuries of time.

2. When the protective cap of vegetation and litter or combination of vegetation, litter and surface rock is broken down by overuse of vegetation, the exposed soil or soil-forming materials erode rapidly.

3. Strata underlying the shallow soil layers are earth or rock materials of great erosive potentialities. Examples of such strata are the deep deposits of marl and clay exposed in New Mexico areas and the horizontal bedrock of the Sierra Ancha Bench Area in Arizona. The former are a potential menace to the life of irrigation works because of the great amount of silt carried from

them to channels of rivers furnishing irrigation water. The latter are a like menace because they produce accelerated run-off which tears out alluvial flood plains of lower drainages and carries the material thus eroded into storage reservoirs.

4. Sub-soils and rock strata underlying the shallow soils on the areas studied are of little value for the production of plant cover. Regeneration of cover on areas depleted of top soil (A horizon soil) is a very slow and difficult process.

V. Preservation of the top soil layer on areas similar to those studied is of the utmost importance. The final conclusion of this study is that this vital soil layer can be preserved by maintaining the density and proportionate composition of herbaceous plant cover which the developed soils and climate of a region will support. This can be accomplished by conservative use of vegetation.

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