Formation of Soils From Parent Materials

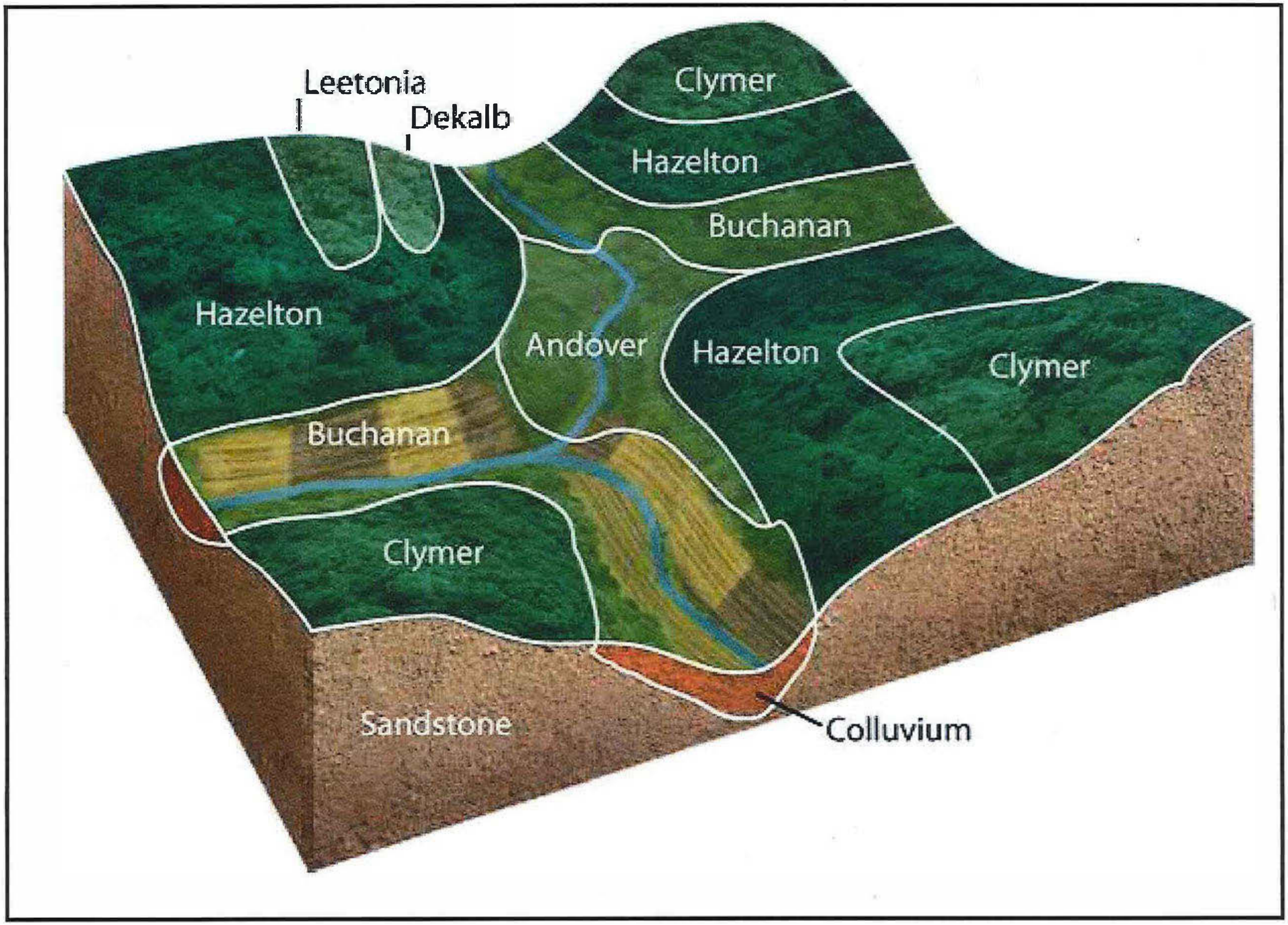
Introduction

This chapter will reveal how rock and earth material at the earth's surface … after coming into contact with water, air and living things, over time … will transform into something new … many different kinds of living soil

Introduction (cont.)

- Every landscape is a suite of different soils…each soil is influencing ecological processes in its own way.
- Whether we intend to modify, exploit, preserve or understand soils…our success depends on knowing how soil properties relate to their environment and to the landscape as a whole.

Soils across a landscape



Rock Composition

- Rocks are formed from discrete chemical compounds called minerals

- Primary minerals are found in and come directly from magma
  - Examples are quartz, feldspars, micas

Rock Composition

- Secondary minerals form from primary minerals further broken down into their chemical constituents through biogeochemical weathering and subsequently reformed into new compounds
  - Examples are clay minerals, calcite, dolomite, gibbsite, goethite, hematite

Weathering

- **Weathering** is the first step of ultimately turning rocks into soil

- Weathering is the physical and chemical breakdown of rocks and rock particles
  - Rocks are destroyed by *physical disintegration* and *chemical decomposition*

Weathering

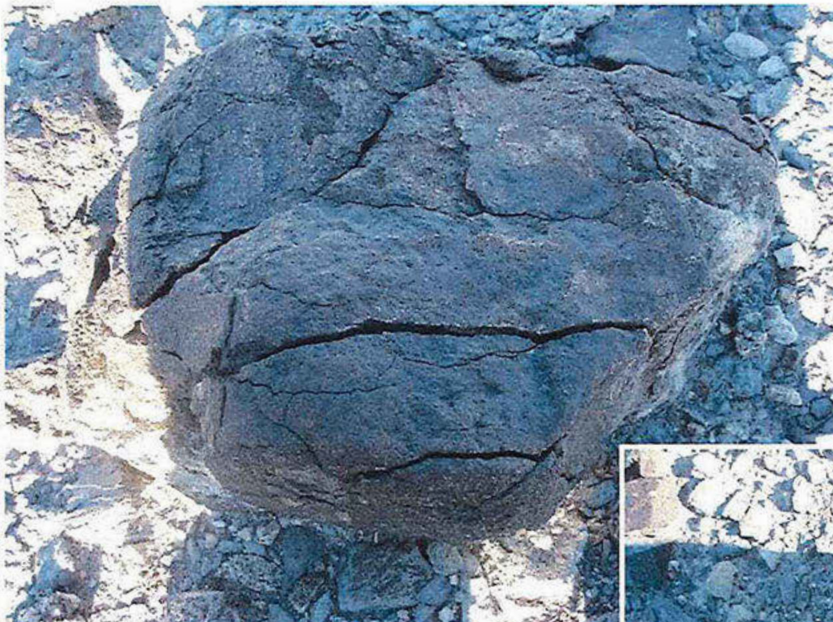
- Physical disintegration (physical weathering) eventually breaks rocks into sand and silt-sized particles
  - Usually particle is composed of one type of mineral

- Chemical decomposition (biogeochemical weathering) decomposes minerals
  - Releases soluble materials and (ultimately) synthesizes new minerals

Physical Weathering

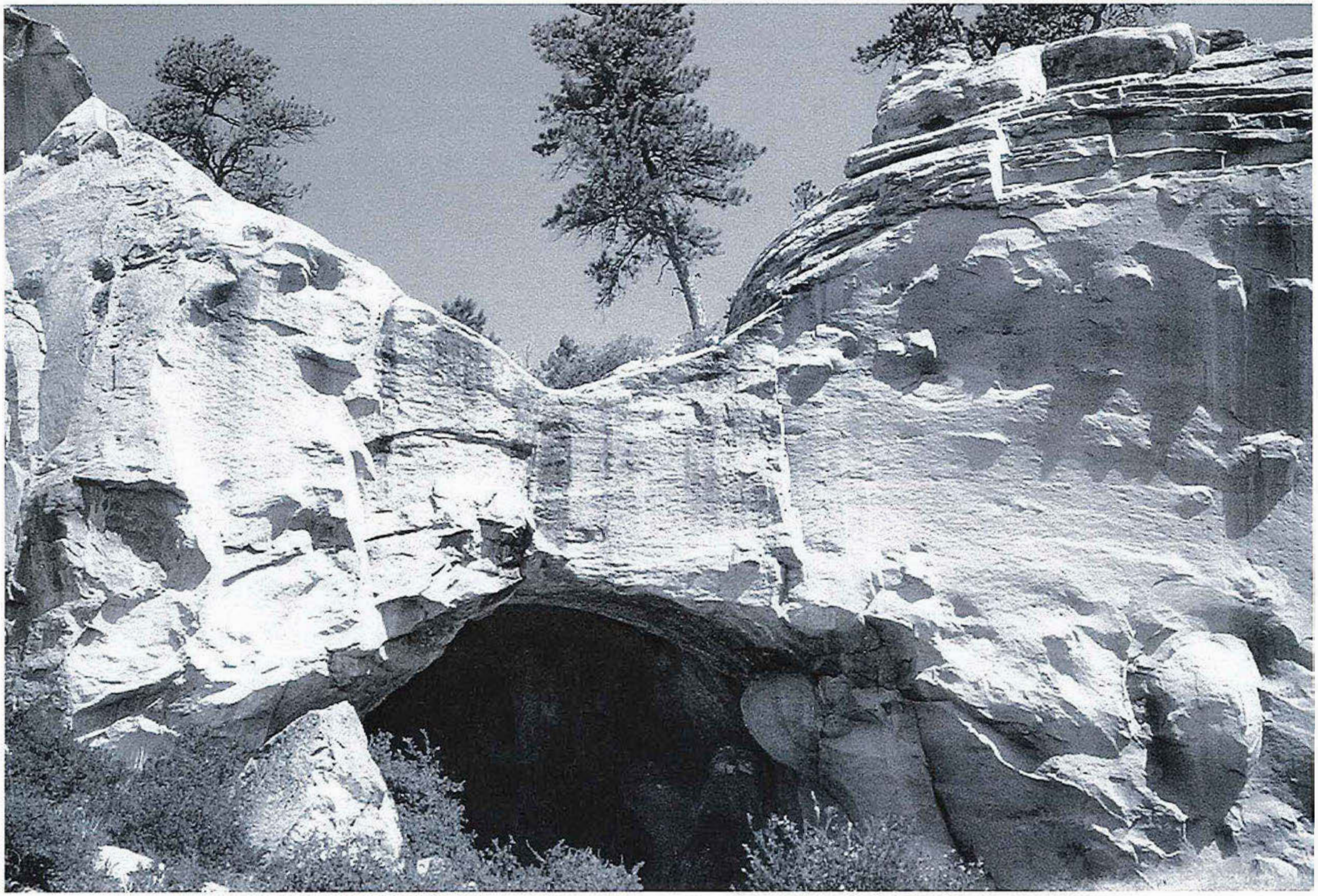
- Temperature
  - Heating and cooling causes expansion and contraction of minerals
  - *Exfoliation*: peeling away of rock layers
- Abrasion by water, ice, and wind
  - Sediment in water
  - Windblown dust and sand
- Plant and animal activities (minor effect)
  - Plant roots in cracks, animals burrowing

Weathering from expansion and contraction due to temperature change



Exfoliation produced by temperature change

Weathering by water (abrasion and dissolution)



Biogeochemical Weathering

- 6 basic biogeochemical weathering reactions exist…all influenced by water
  - *Hydration:* minerals become more stable by combining with intact water molecule
  - *Hydrolysis:* water molecules split into hydrogen and hydroxyl components
    - Components react with minerals or exchange with cations to form new compounds

Biogeochemical Weathering

- *Dissolution:* certain components and minerals dissolve and leach away as they are hydrated with water
  - Salt dissolving in water

- *Carbonation:* formation of acids from carbon dioxide and water
  - increases *dissolution* of some minerals

Weathering by dissolution and carbonation

Evidence of physical (root action) and biogeochemical (dissolution) weathering

Biogeochemical Weathering

- *Oxidation-reduction:* minerals and compounds transfer electrons or combine with 0_2, forming new compounds
  - oxidation of iron (loss of electron)

- *Complexation:* soil biological processes produce organic acids
  - form complexes with ions held within minerals, destroys structure of mineral

Oxidation and hydration (bands of varying color)

Introduction to Soil-Forming Factors

Soils vary greatly from one location to another in the world.

The type of soil formed at any one location depends on the nature and interaction of *parent material, climate, living organisms, topography,* and *time*

These are the 5 soil-forming factors.

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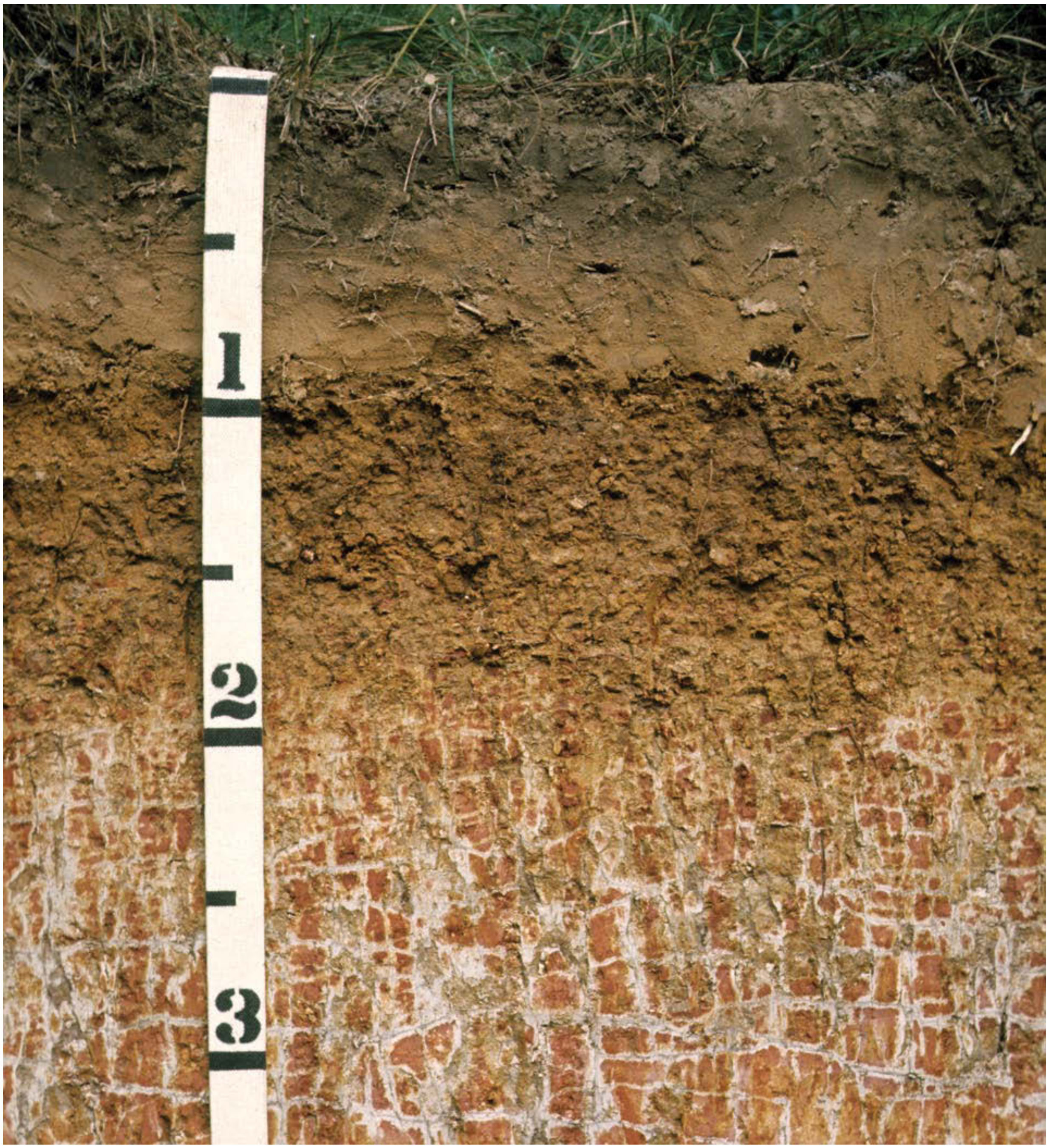
From the Surface Down

An Introduction to Soil Surveys for Agronomic Use

Second Edition



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Cover

Profile of Segno fine sandy loam, a Plinthic Paleudalf. Note the characteristic blocks of plinthite at a depth of 30 inches.

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Section 2: How is soil formed?

Figure 12 shows common landscapes. Soils form through the interactions of climate, living organisms, and landscape position as they influence the decomposition and transformation of parent material over time. Figure 12 shows how soil profiles change from weakly developed to well developed with time. Generally, soils on older terraces or second bottoms have a developed B horizon, unlike recent soils on first bottoms. The recent soils may have strata varying in thickness, texture, and composition and may have begun accumulating humus in the surface layer.

Differences in climate, parent material, landscape position, and living organisms from one location to another and the amount of time the material has been in place all influence the soil-forming process.

Five soil-forming factors
Parent material
Climate
Living organisms
Landscape position
Time

Parent material

Parent material refers to the great variety of unconsolidated organic material (such as fresh peat) and mineral material in which soil formation begins. Mineral material includes partially weathered rock; ash from volcanoes; sediments moved and deposited by wind, water, or gravity; and ground-up rock deposited by glacial ice. The material has a strong effect on the type of soil that forms and the rate at which it forms. Soil formation may take place more quickly in materials that are more permeable to water (fig. 8). Dense, massive, clayey materials can be resistant to the processes of soil formation (fig. 7). In soils that formed in sandy material, the A horizon may be a little darker than its parent material, but the B horizon tends to have a similar color, texture, and chemical composition (fig. 13).

Climate

Climate is a major factor in determining the kind of plant and animal life on and in the soil. It determines the amount of water available for weathering minerals and for transporting the minerals and elements released.

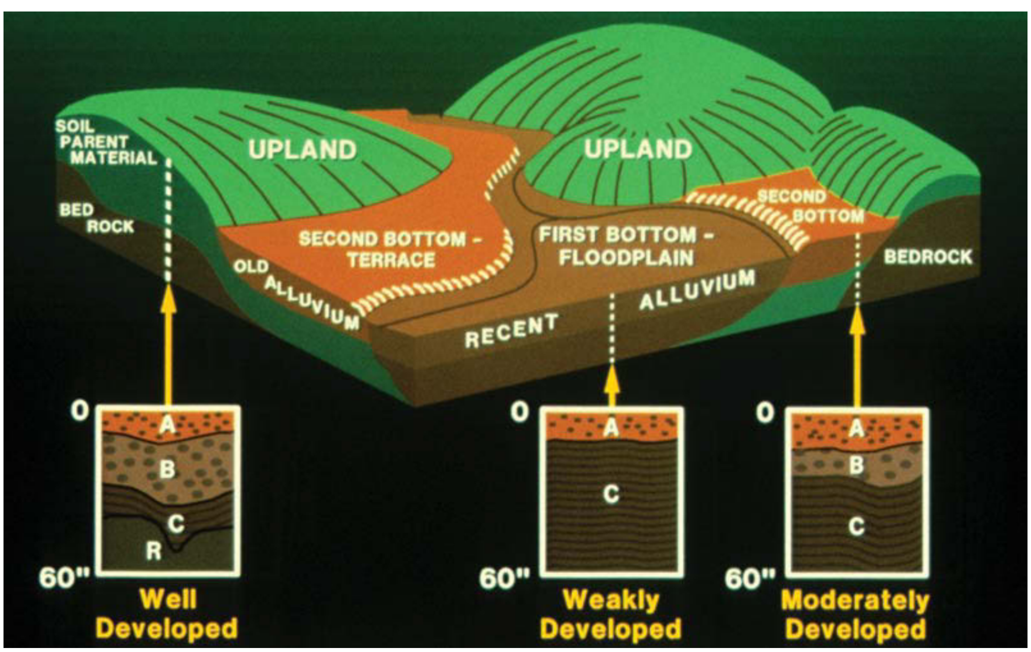


Figure 12.—Landscape position, climate, time, living organisms, and parent material influence soil formation.

The soil in figure 14 formed in drier regions than the soil in figure15. Through its influence on soil temperature, climate determines the rate of chemical weathering.

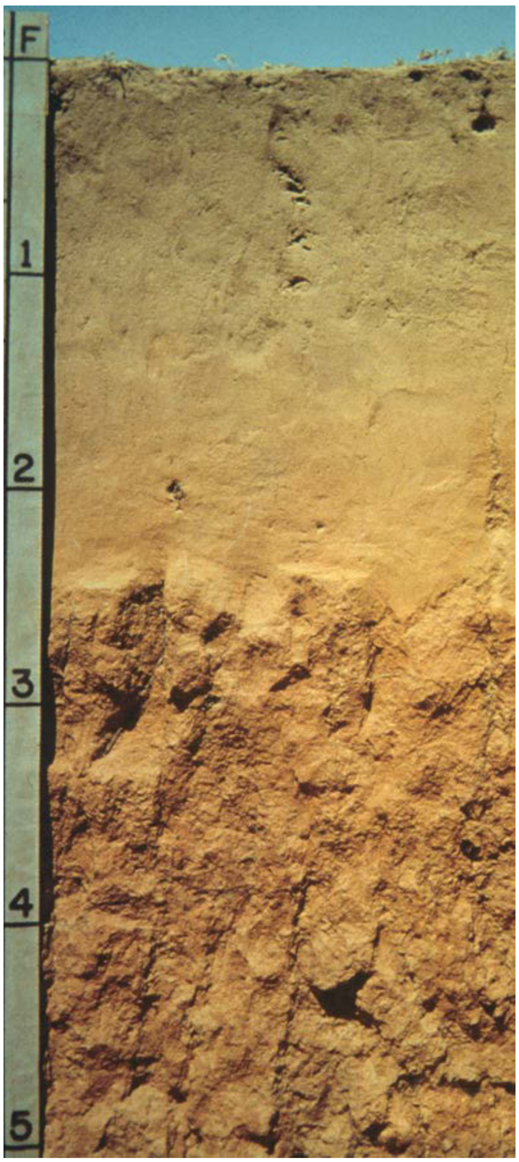


Figure 13.—Well drained Brownfield soil formed in old eolian material. Light brown fine sand (0 to 30 inches) over red and yellowish red sandy clay loam (30 to 60 inches). Arenic Aridic Paleustalf. New Mexico and Texas.

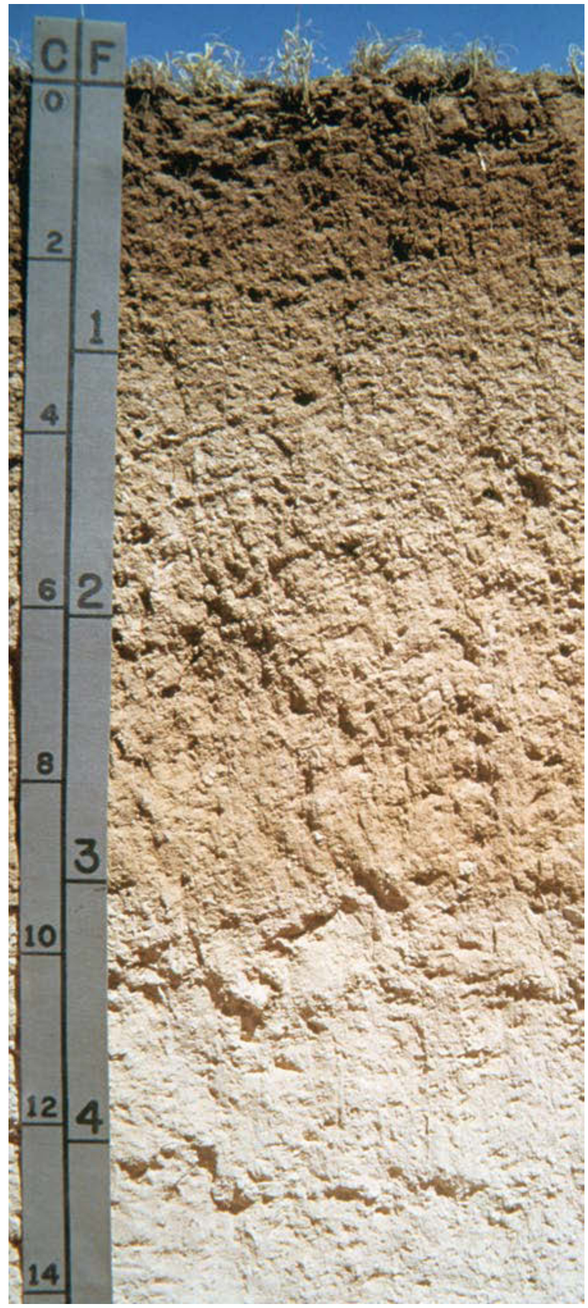


Figure 14.—Well drained Clovis soil formed in thick, loamy sediments on fans and plains of old alluvium. The accumulation of calcium carbonate increases with depth, beginning at a light brown loam Bk horizon at 10 inches. Ustic Calciargid. New Mexico, east-central Arizona, and southwestern Utah.

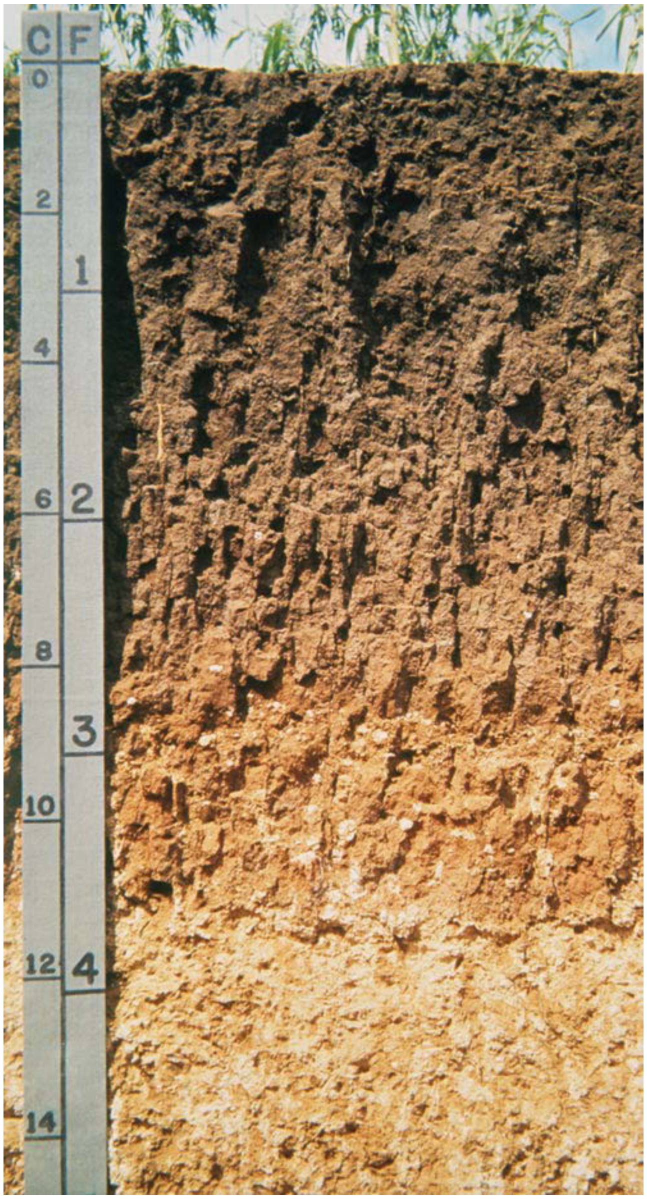


Figure 15.—Well drained Olton soil formed in mixed alluvial and eolian material. Ap horizon (0 to 6 inches) of brown loam; Bt horizon (6 to 32 inches) of reddish brown clay loam; whitish calcium carbonate below the Bt horizon. Aridic Paleustoll. Texas and New Mexico high plains.

Warm, moist climates encourage rapid plant growth and thus high organic-matter production. Also, they accelerate organic-matter decomposition. The opposite is true for cold, dry climates. Under the control of climate, freezing, thawing, wetting, and drying break parent material apart.

Rainfall causes leaching. Rain dissolves some minerals, such as carbonates, and transports them deeper into the soil. Some acid soils formed in parent material that originally contained limestone. Rainfall can also be acid, especially downwind from industrial processes.

Living organisms

Plants affect soil formation by supplying upper layers with organic matter, recycling nutrients from lower to upper layers, and helping to control erosion. In general, deep-rooted plants contribute more to soil formation than shallow-rooted plants because the passages they create allow greater water movement, which in turn aids in leaching. Leaves, twigs, and bark from large plants fall onto the soil and are broken down by fungi, bacteria, insects, earthworms, and burrowing animals. These organisms eat and break down organic matter, releasing plant nutrients. Some change certain elements, such as sulfur and nitrogen, into usable forms for plants.

Microscopic organisms and the humus they produce act as a kind of glue, holding soil particles together in aggregates. Well-aggregated soil provides the right combination of air and water to plant roots.

Landscape position

Landscape position causes local changes in moisture and temperature. When rain falls on a landscape, water begins to move downward by the force of gravity, either through the soil or across the surface to a lower elevation. In an area where climate, living organisms, parent material, and time are held constant, the drier upslope soils may be quite different from the wetter soils at the base of the slope, where water accumulates. The wetter soils may have reducing conditions that will inhibit proper root growth for plants that require a balance of soil oxygen, water, and nutrients.

The steepness, shape, and length of slopes are important because they influence the rate at which water flows into or off the soil. If unprotected, the more sloping soils may become eroded and thus have a thinner surface layer. Eroded soils tend to be less fertile and have less available water than uneroded soils of the same series.

Aspect affects soil temperature and moisture. In most of the continental United States, soils on north-facing slopes tend to be cooler and wetter than soils on south-facing slopes. These differences affect seedling emergence and the rate of plant growth. Soils on north-facing slopes tend to have thicker A and B horizons.

Time

Time is required for horizon formation. The longer a soil surface has been exposed to soil-forming agents, such as rain and growing plants, the greater the development of the soil profile. Soils in areas of recent alluvial or windblown material and soils on steep slopes where erosion has been active may show very little evidence of horizon development (fig. 3).

Soils on the older, stable surfaces generally have well defined horizons because the rate of soil formation has exceeded the rate of geologic erosion or deposition (fig. 6). As soils age, many original minerals are destroyed. Many new ones are formed. Soils become more leached, more acid, and more clayey. In many well drained soils, the B horizons tend to become redder as iron accumulates with time (figs. 8 and 15).

Section 3: What are the soil-forming processes?

The four major processes that change parent material into soil are additions, losses, translocations, and transformations.

Processes of soil formation
- Additions
- Losses
- Translocations
- Transformations

Additions

The most obvious addition is the accumulation of organic matter. As soon as plants begin to grow in fresh parent material, organic matter begins to accumulate. Organic matter gives a black or dark brown color to the surface layer (fig. 6). Even young soils may have a dark surface layer (fig. 3). Most additions of organic matter to the surface increase the cation-exchange capacity and the supply and availability of plant nutrients.

Additions may occur during periods of rainfall or during periods when eolian (windblown) material is deposited (fig. 13). On the average, rainfall adds about 5 pounds of nitrogen per acre per year. It also adds other elements and fine mineral particles. By causing rivers to flood, rainfall is indirectly responsible for the addition of new sediment to the soil on a flood plain.

Other additions occur via gravity in areas where soils creep or are eroded. Soil material from these areas is deposited in downslope areas.

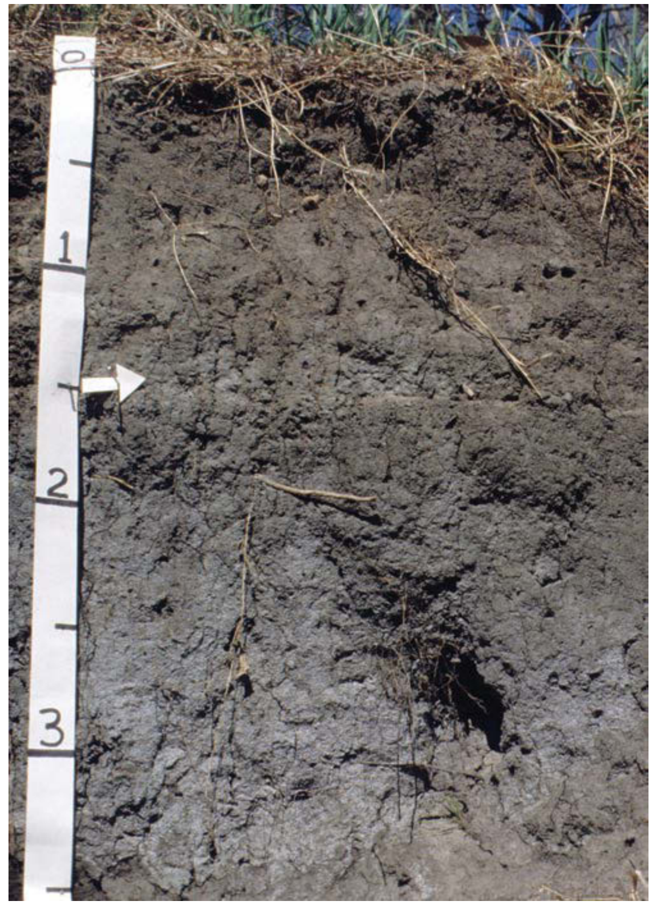


Figure 16.—Somewhat poorly drained Salmo soil, which has strata of alluvial material with textures of fine sandy loam and silt loam (0 to 18 inches) and has an accumulation of soluble salts at a depth of 24 inches. Cumulic Endoaquoll. South Dakota and Nebraska.

Losses

Most losses occur through leaching. Water moving through the soil dissolves certain minerals and transports them into deeper layers. Some materials, especially sodium salts, gypsum, and calcium carbonate, are relatively soluble (figs. 14, 15, and 16). They are removed early during soil formation. Carbonates generally are removed from the upper horizons of soils in humid regions or are leached out of the soils entirely. Quartz, aluminum, iron oxides, and kaolinitic clay weather slowly. They become the main components of highly weathered soil.

Fertilizers are relatively soluble, and many, such as nitrogen and potassium, are readily lost through leaching caused either by natural rainfall or by irrigation water. Long-term use of fertilizers based on ammonium may acidify the soil and contribute to the loss of carbonates in some areas.

Oxygen is a gas that is released into the atmosphere by growing plants. Carbon dioxide is consumed by the growing plants, but it is lost from the soil as fresh organic matter decays. When soil is wet, nitrogen can be changed to a gas and lost to the atmosphere.

Solid mineral and organic particles are lost through erosion. Such losses can be serious because the material lost is generally from the most productive part of the soil profile. On the other hand, the sediment relocated to the lower slope positions or deposited on bottom lands can increase or decrease the productive use of the soils in those areas.

Translocations

Translocation is the movement of soil material from one place to another. In areas of low rainfall, leaching often is incomplete. Water starts moving down through the soil, dissolving soluble minerals as it goes. There is not enough water, however, to move the minerals all the way through the soil. When the water stops moving and then evaporates, salts are left behind. Soil layers with accumulations of calcium carbonate or other salts form in this way. If this cycle occurs enough times, a calcareous hardpan can form.

Upward translocation and lateral movement occur in some soils. Low-lying soils can have a high water table, even if they are in dry areas. Evaporation at the surface causes water to move upward (fig. 16). Salts are dissolved on the way. They are deposited on the surface as the water evaporates (fig. 17).

Transformations

Transformations are changes that take place in the soil. Micro-organisms that live in the soil feed on fresh organic matter and change it into humus. Chemical weathering changes the parent material. Some minerals are destroyed completely. Others are changed into new minerals. Many of the clay-sized particles in soil are actually new minerals that form during soil development.

Figure 17.—Salinity-alkalinity problem caused by poor internal soil drainage. California.

Other transformations can change the form of certain materials. Iron oxides (ferric form) usually give soils a yellowish or reddish color. In waterlogged soils, however, iron oxides lose some of their oxygen and are considered reduced. The reduced form of iron (ferrous) is easily removed from the soil through leaching. After the iron is gone, the leached zone generally is grayish or whitish (fig. 8).

Repeated cycles of saturation and drying create mottles (splotches of colored soil in a matrix of a different color). Part of the soil is gray because iron oxide is reduced or lost, and the part in which the iron oxide is not removed or reduced is browner (figs. 18 and 19). During long periods of saturation, gray-lined root channels develop. These may indicate a possible loss of iron caused by enhanced microbial activity following an addition of humus from decayed roots.

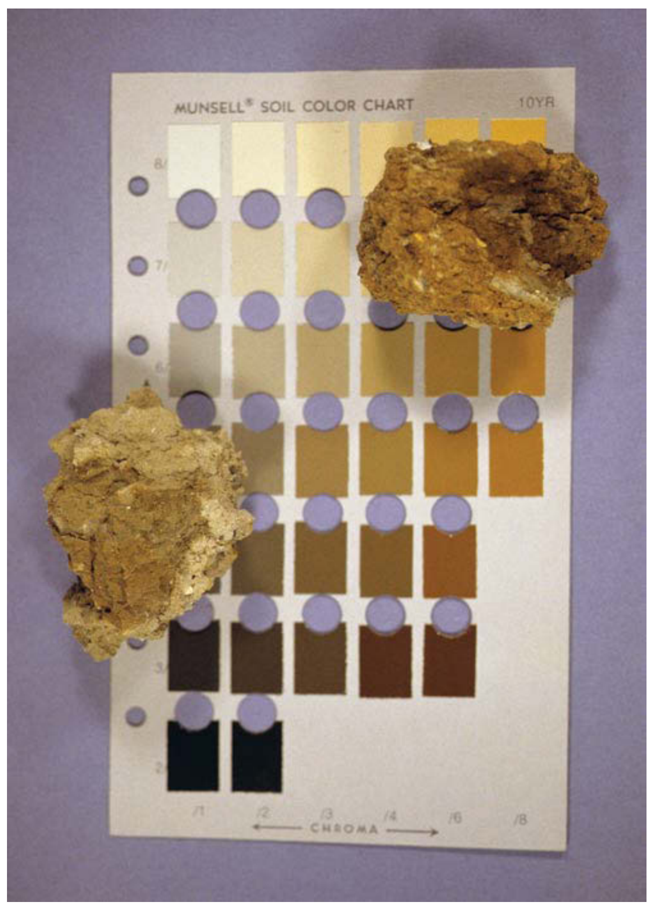


Figure 18.—Munsell soil color. The soil block on the left has gray reduced colors. The one on the right has reddish oxidized colors.

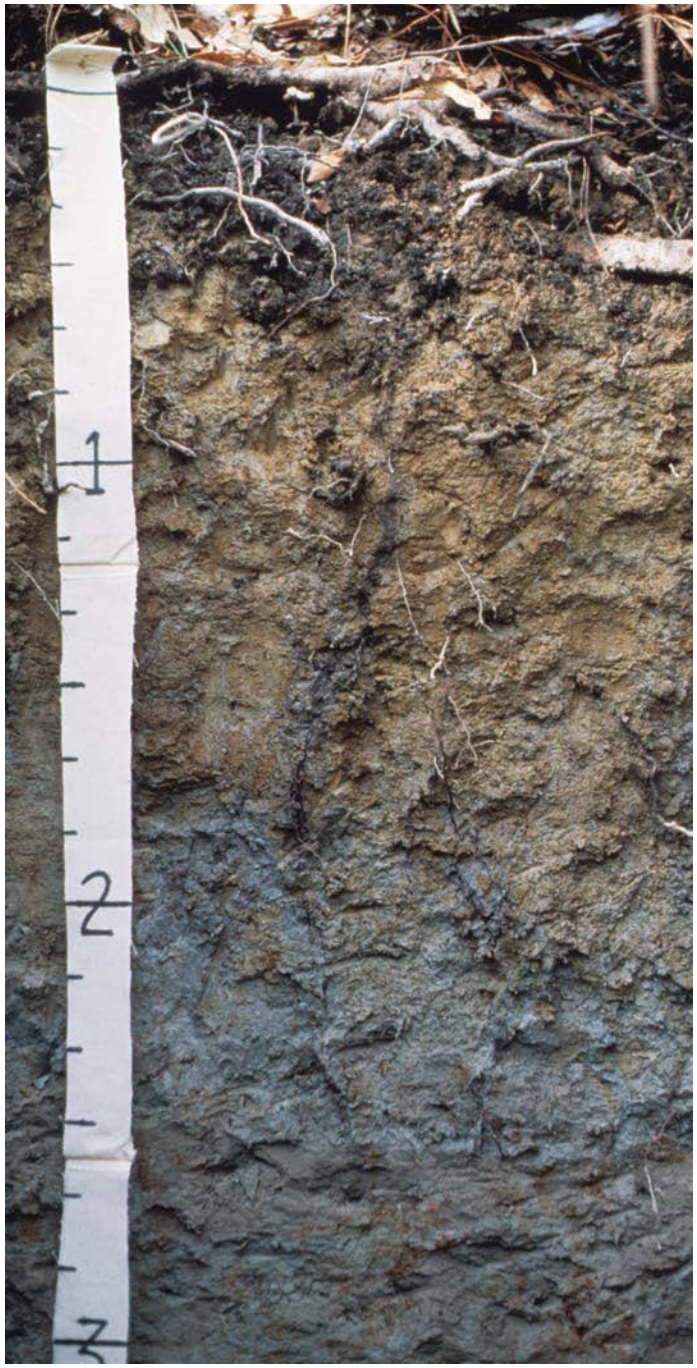


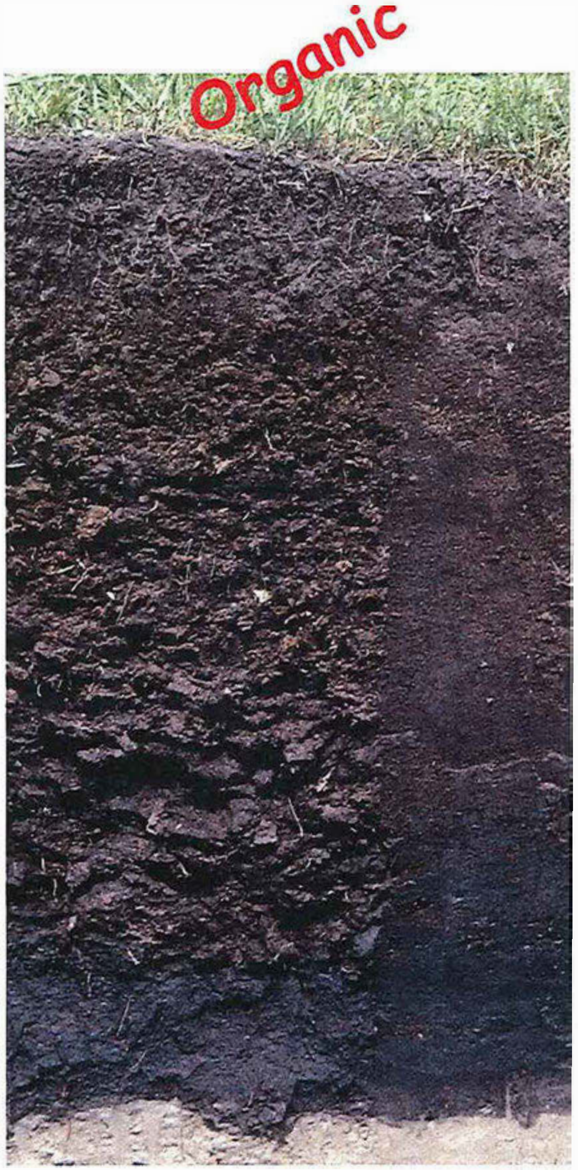
Figure 19.—Moderately well drained Mattapex soil, wet phase, formed in marine sediments. Dark grayish brown A horizon (0 to 6 inches); brown BE horizon (6 to 12 inches); yellowish brown, strongly acid Bt horizon (12 to 36 inches). Common light brownish gray mottles are in the part of the Bt horizon between depths of 21 and 36 inches. A C horizon is at a depth of 36 inches. Aquic Hapludult. Maryland, Delaware, Virginia, and New Jersey.

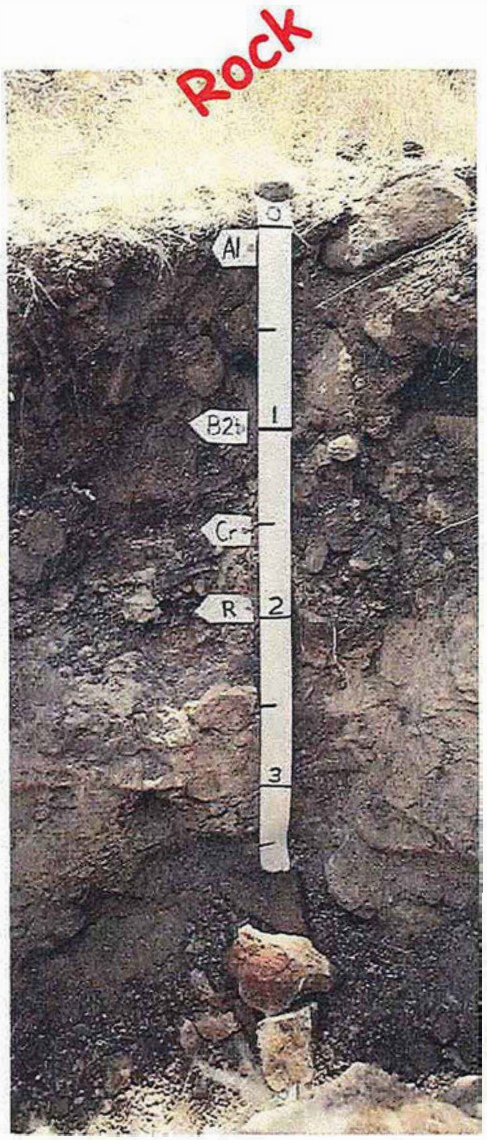
Weathering and Parent Material

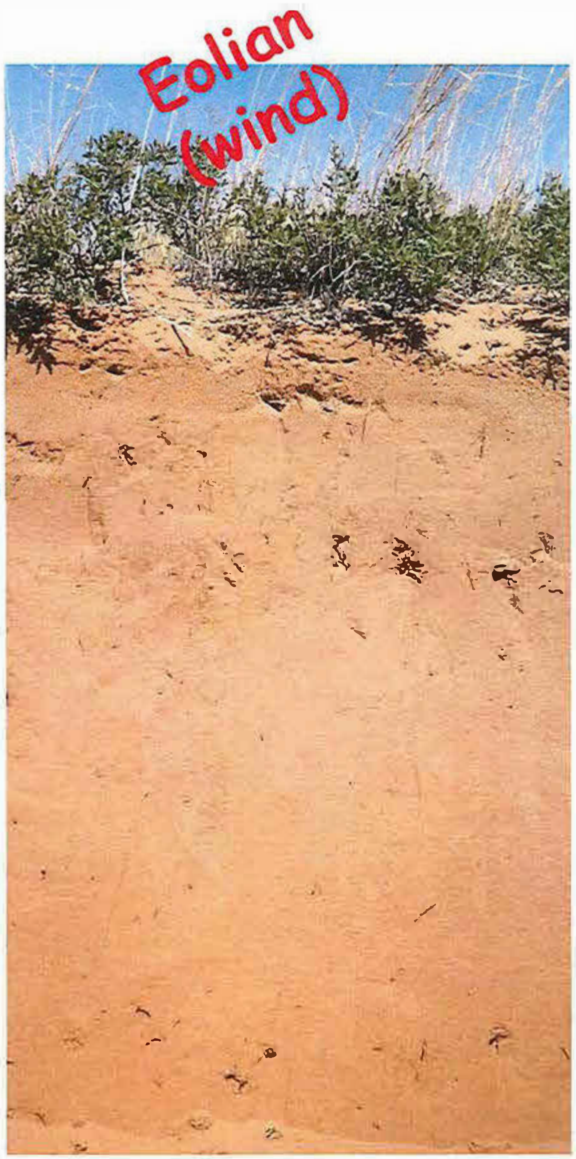
Weathering is the process (or processes) through which the rocks at the earth's surface are broken down into the material out of which the soil will eventually form…this material is called…

parent material

Examples of Parent Material







Parent Material (factor 1)

The material **IN** which the soil forms

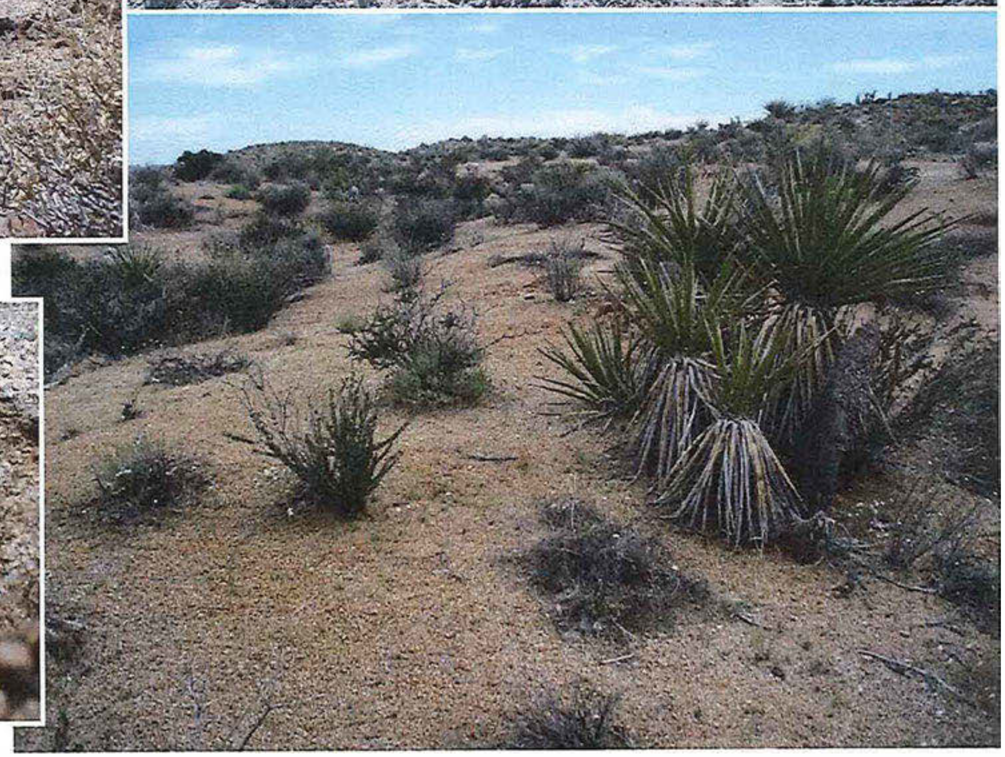
- *Residual parent material:* formed in place from weathering of underlying bedrock

- *Transported parent material:* material was moved to site of current soil formation

Classification of Parent Materials

- *Residual*
  - Residuum: formed in place from bedrock
  - Organic (peat) deposits: accumulation of organic material in wet places

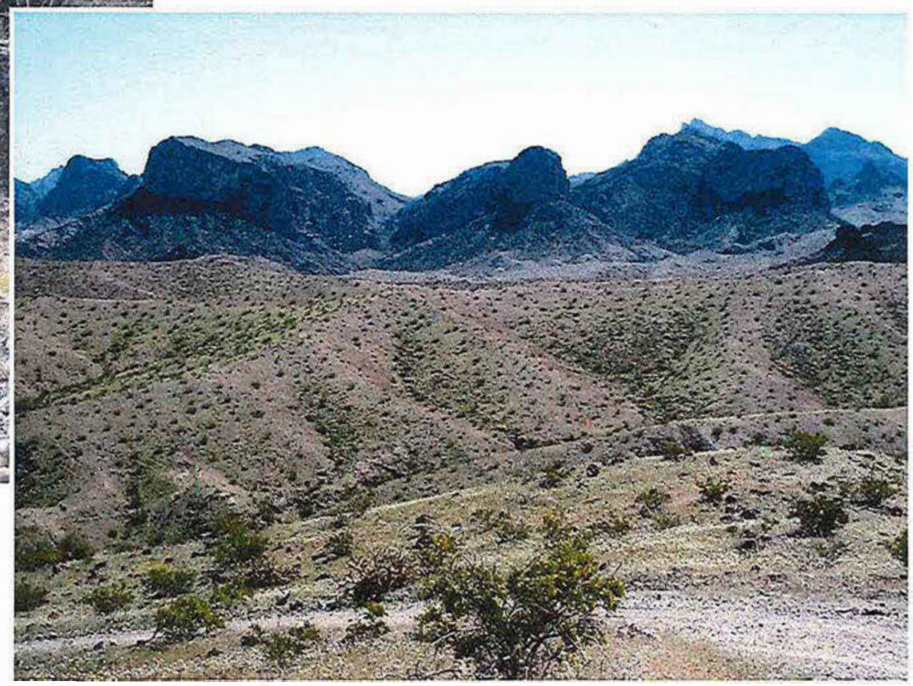
Residuum



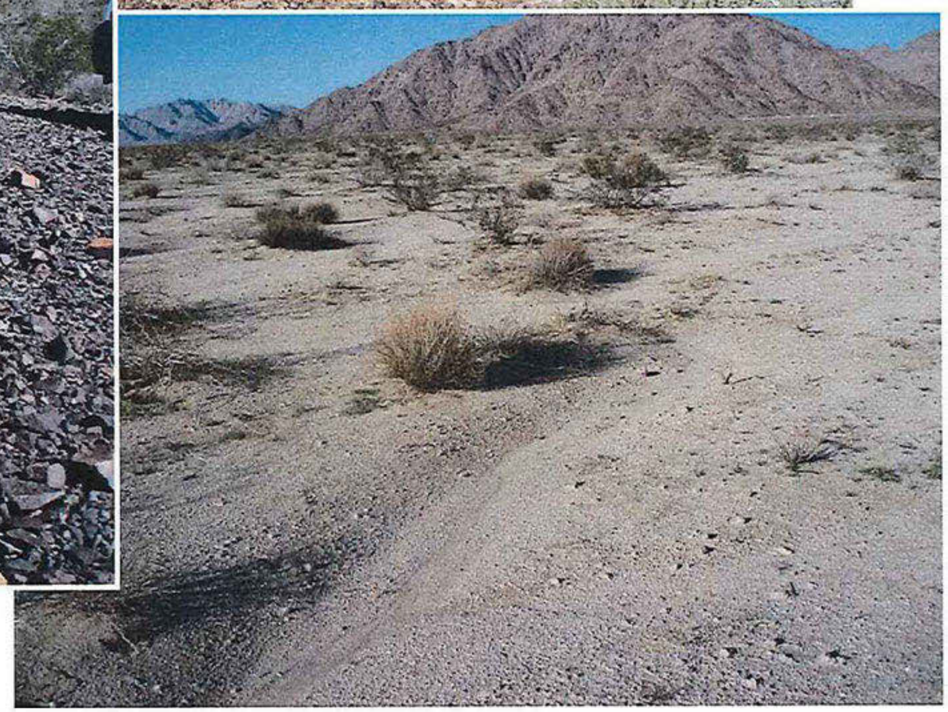
Classification of Parent Materials

- *Transported*
  - Colluvial (colluvium): transported by gravity
  - Alluvial (alluvium): transport by water
    - Deposited on river floodplains, alluvial fans, and deltas

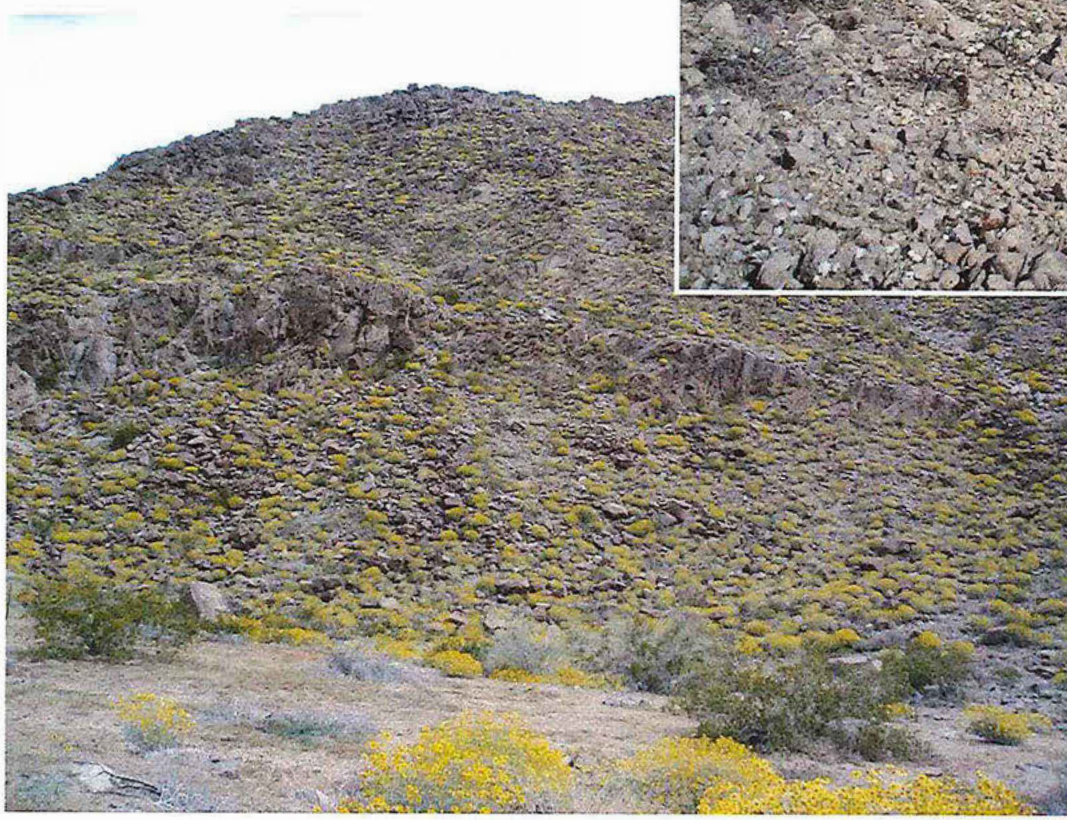
Residuum (background) & Alluvium (foreground)



Alluvium



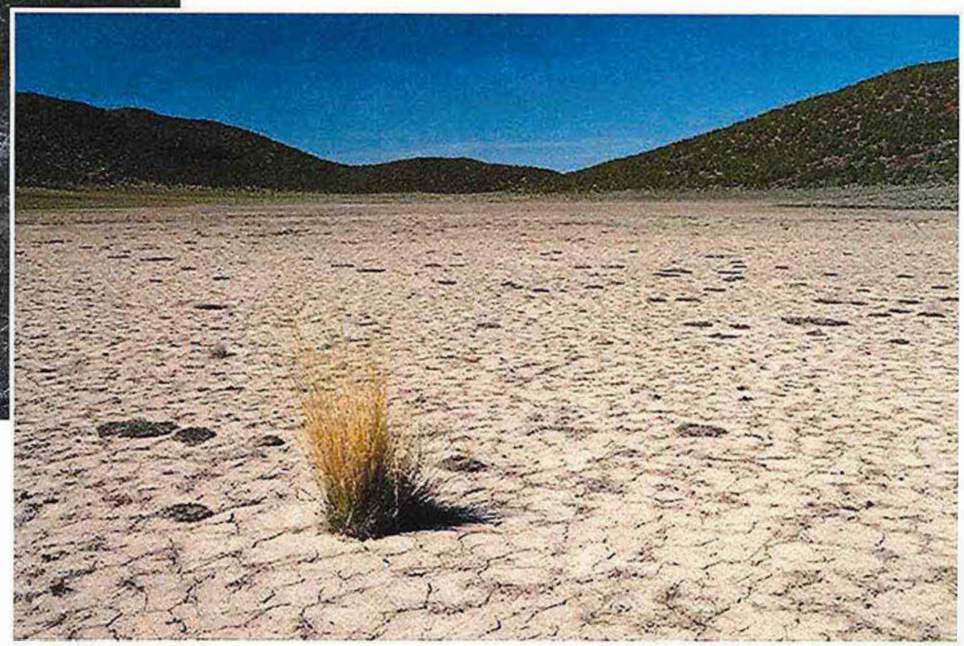
Colluvium



Classification of Parent Materials

- *Transported (continued)*
  - Marine: transport by water
    - Deposited in oceans, estuaries, and gulfs
  - Lacustrine: transport by water
    - Deposited in lakes

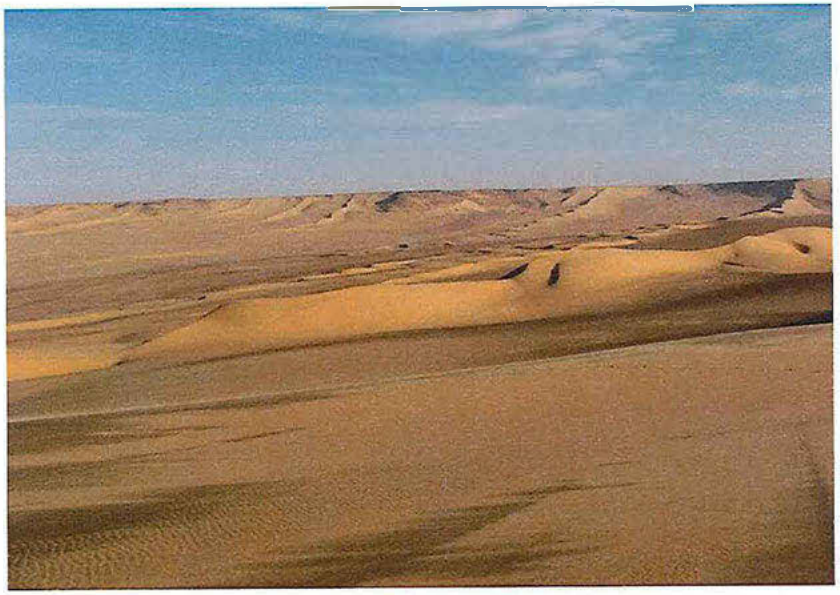
Lacustrine



Classification of Parent Materials

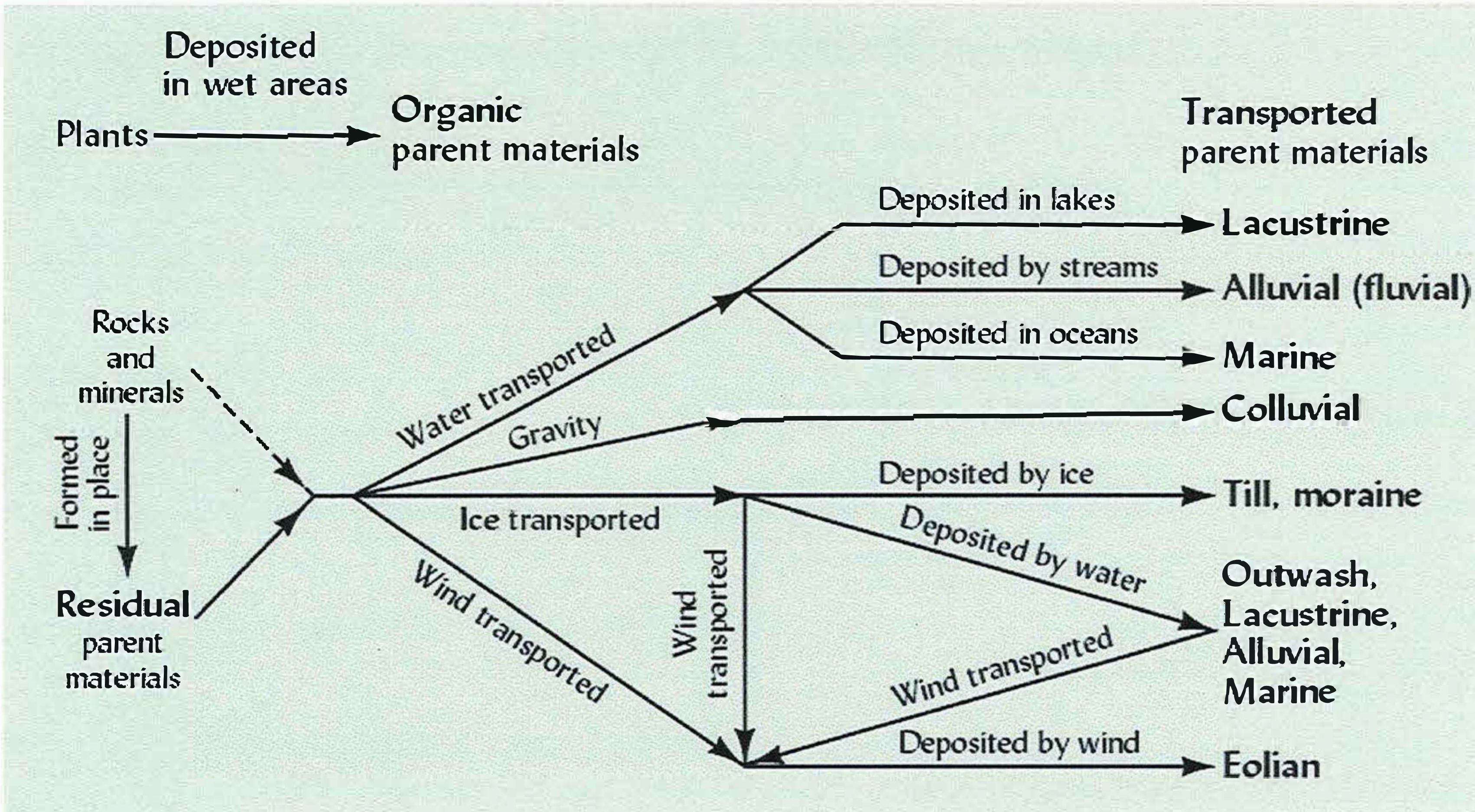
- *Transported (continued)*
  - Eolian: transport by wind
    - Dune sand, loess, aerosolic dust, volcanic ash
  - Glacial: transport by ice
    - Glacial till = ground up rocks etc.

Eolian



Glacial

Summary of parent material formation, transportation and deposition



The ground surface may be divided into fine earth and material other than fine earth. The latter consists of rock fragments and both alive and dead vegetation. Vegetation is separated into canopy and noncanopy. A canopy component has a relatively large cross sectional area capable of intercepting rainfall compared to the area near enough to the ground surface to affect overland water flow. In practice, the separation of canopy from noncanopy should be coordinated with the protocols for computation of susceptibility to erosion. Noncanopy material is commonly referred to as mulch. It includes rock fragments and vegetation.

The first step in evaluation is to decide upon the ground surface cover components. The number is usually one to three. A common three-component land surface consists of trees, bushes, and areas between the two. The areal proportion of each component must be established. This may be done by transect. If a canopy component is present, the area within the drip line as a percent of the ground surface is determined. For each canopy component, the effectiveness must be established. Effectiveness is the percent of vertical raindrops that would be intercepted. Usually the canopy effectiveness is estimated visually, but a spherical densitometer may be used. In addition to the canopy effectiveness, the mulch (rock fragments plus vegetation) must be established for each component.

Transect techniques may be employed to determine the mulch percentage. The mulch can be subdivided into rock fragments and vegetation. From the areal proportions of the components and their respective canopy efficiencies and mulch percentages, the soil-loss ratio may be computed for the whole land surface (Wischmeier, 1978). In addition to the observations for the computation of the soil-loss ratio, information may be obtained about the percent of kinds of plants, size of rock fragments, amount of green leaf area, and aspects of color of the immediate surface that would affect absorption of radiant energy in an area.

Parent Material

Parent material refers to unconsolidated organic and mineral materials in which soils form. The parent material of a genetic horizon cannot be observed in its original state; it must be inferred from the properties that the horizon has inherited and from other evidence. In some soils, the parent material has changed little, and what it was like can be deduced with confidence. In others, such as some very old soils of the tropics, the specific kind of parent material or its mode or origin is speculative.

Much of the mineral matter in which soils form is derived in one way or another from hard rocks. Glaciers may grind the rock into fragments and earthy material and deposit the mixture of particles as glacial till. On the other hand, rock may be weathered with great chemical and physical changes but not moved from its place of origin; this altered material is called "residuum from rock."

In some cases, little is gained from attempting to differentiate between geologic weathering and soil formation because both are weathering processes. It may be possible to infer that a material was weathered before soil formation. The weathering process causes some process constituents to be lost, some to be transformed, and others to be concentrated.

Parent material may not necessarily be residuum from the bedrock that is directly below, and the material that developed into a modern soil may be unrelated to the underlying bedrock. Movement of soil material downslope is an important process and can be appreciable even on gentle slopes, especially on very old landscapes. Also, locally associated soils may form in sedimentary rock layers that are different.

Seldom is there certainty that a highly weathered material weathered in place. The term "residuum" is used when the properties of the soil indicate that it has been derived from rock like that which underlies it and when evidence is lacking that it has been modified by movement. A rock fragment distribution that decreases in amount with depth, especially over saprolite, indicates that soil material probably has been transported downslope. Stone lines, especially if the stones have a different lithology than the underlying bedrock, provide evidence that the soil did not form entirely in residuum. In some soils, transported material overlies residuum and illuvial organic matter and clay are superimposed across the discontinuity between the contrasting materials. A certain degree of landscape stability is inferred for residual soils. A lesser degree is inferred for soils that developed in transported material.

Both consolidated and unconsolidated material beneath the solum that influence the genesis and behavior of the soil are described in standard terms. Besides the observations themselves, the scientist records his judgment about the origin of the parent material from which the solum developed. The observations must be separated clearly from inferences.

The lithologic composition, structure and consistence of the material directly beneath the solum are important. Evidence of stratification of the material—textural differences, stone lines, and the like—need to be noted. Commonly, the upper layers of outwash deposits settled out of more slowly moving water and are finer in texture than the lower layers. Windblown material and volcanic ash are laid down at different rates in blankets of varying thickness. Examples of such complications are nearly endless.

Where alluvium, loess, or ash are rapidly deposited on old soils, buried soils may be well preserved. Elsewhere the accumulation is so slow that the solum thickens only gradually. In such places, the material beneath the solum was once near the surface but may now be buried below the zone of active change.

Where hard rocks or other strongly contrasting materials lie near enough to the surface to affect the behavior of the soil, their depths need to be measured accurately. The depth of soil over such nonconforming materials is an important criterion for distinguishing different kinds of soil.

Geological materials need to be defined in accordance with the accepted standards and nomenclature of geology. The accepted, authoritative names of the geological formations are recorded in soil descriptions where these can be identified with reasonable accuracy. As soil research progresses, an increasing number of correlations are being found between particular geological formations and the mineral and nutrient content of parent materials and soils. For example, certain terrace materials and deposits of volcanic ash that are different in age or source, but otherwise indistinguishable, vary widely in the content of cobalt. Wide variations in the phosphorus content of two otherwise similar soils may reflect differences in the phosphorus content of two similar limestones that can be distinguished in the field only by specific fossils.

Igneous rocks formed by the solidification of molten materials that originated within the earth. Examples of igneous rocks that weather to important soil material are granite, syenite, basalt, andesite, diabase, and rhyolite.

Sedimentary rocks formed from sediments laid down in previous geological ages. The principal broad groups of sedimentary rocks are limestone, sandstone, shale, and conglomerate. There are many varieties of these broad classes of sedimentary rocks; for example, chalk and marl are soft varieties of limestone. Many types are intermediate between the broad groups, such as calcareous sandstone and arenaceous limestone. Also included are deposits of diatomaceous earth, which formed, from the siliceous remains of primitive plants called diatoms.

Metamorphic rocks resulted from profound alteration of igneous and sedimentary rocks by heat and pressure. General classes of metamorphic rocks important as parent material are gneiss, schist, slate, marble, quartzite, and phyllite.

The principal broad subdivisions of parent material are discussed in the following paragraphs.

Material Produced by Weathering of Rock in Place

The nature of the original rock affects the kinds of material produced by weathering. The rock may have undergone various changes, including changes in volume and loss of minerals—plagioclase feldspar and other minerals. Rock may lose mineral material without any change in volume or in the original rock structure, and saprolite is formed. Essentially, saprolite is a parent material. The point where rock weathering ends and soil formation begins is not always clear. The processes may be consecutive and even overlapping. Quite different soils may form from similar or even identical rocks under different weathering conditions. Texture, color, consistence, and other characteristics of the material should be included in the description of soils, as well as important features such as quartz dikes. Useful information about the mineralogical composition, consistence, and structure of the parent rock itself should be added to help in understanding the changes from parent rock to weathered material.

Transported Material

The most extensive group of parent materials is the group that has been moved from the place of origin and deposited elsewhere. The principal groups of transported materials are usually named according to the main agent responsible for their transport and deposition. In most places, sufficient evidence is available to make a clear determination; elsewhere, the precise origin is uncertain.

In soil morphology and classification, it is exceedingly important that the characteristics of the material itself be observed and described. It is not enough simply to identify the parent material. Any doubt of the correctness of the identification should be mentioned. For example, it is often impossible to be sure whether certain silty deposits are alluvium, loess, or residuum. Certain mud flows are indistinguishable from glacial till. Some sandy glacial till is nearly identical to sandy outwash. Fortunately, hard-to-make distinctions are not always of significance for soil behavior predictions.

Material moved and deposited by water

Alluvium.—Alluvium consists of sediment deposited by running water. It may occur on terraces well above present streams or in the normally flooded bottom land of existing streams. Remnants of very old stream terraces may be found in dissected country far from any present stream. Along many old established streams lie a whole series of alluvial deposits in terraces—young deposits in the immediate flood plain, up step by step to the very old deposits on the highest terraces. In some places recent alluvium covers older terraces.

Lacustrine deposits.—These deposits consist of material that has settled out of bodies of still water. Deposits laid down in fresh-water lakes associated directly with glaciers are commonly included as are other lake deposits, including some of Pleistocene age that are not associated with the continental glaciers. Some lake basins in the Western United States are commonly called playas; the soils in these basins may be more or less salty, depending on climate and drainage.

Marine sediments.—These sediments settled out of the sea and commonly were reworked by currents and tides. Later they were exposed either naturally or following the construction of dikes and drainage canals. They vary widely in composition. Some resemble lacustrine deposits.

Beach deposits.—Beach deposits mark the present or former shorelines of the sea or lakes. These deposits are low ridges of sorted material and are commonly sandy, gravelly, cobbly, or stony. Deposits on the beaches of former glacial lakes are usually included with glacial drift.

Material moved and deposited by wind

Windblown material can be divided into groups based on particle size or on origin. Volcanic ash and cinders are examples of materials classed by both particle size and origin. Other windblown material that is mainly silty is called loess, and that which is primarily sand is called eolian sand. Eolian sand is commonly but not always in dunes. Nearly all textures intermediate between silty loess and sandy dune material can be found.

Volcanic ash, pumice, and cinders are sometimes regarded as unconsolidated igneous rock, but they have been moved from their place of origin. Most have been reworked by wind and, in places, by water. Ash is volcanic ejecta smaller than 2 mm. Ash smaller than 0.05 mm may be called "fine ash." Pumice and cinders are volcanic ejecta 2 mm or larger.

Loess deposits typically are very silty but may contain significant amounts of clay and very fine sand. Most loess deposits are pale brown to brown, although gray and red colors are common. The thick deposits are generally massive and have some gross vertical cracking. The walls of road cuts in thick loess stand nearly vertical for years. Other silty deposits that formed in other ways have some or all of these characteristics. Some windblown silt has been leached and strongly weathered so that it is acid and rich in clay. On the other hand, some young deposits of windblown material (loess) are mainly silt and very fine sand and are low in clay.

Sand dunes, particularly in warm, humid regions, characteristically consist of fine or medium sand that is high in quartz and low in clay-forming materials. Sand dunes may contain large amounts of calcium carbonate or gypsum, especially in deserts and semideserts.

During periods of drought and in deserts, local wind movements may mix and pile up soil material of different textures or even material that is very rich in clay. Piles of such material have been called "soil dunes" or "clay dunes." Rather than identify local accumulations of mixed material moved by the wind as "loess" or "dunes," however, it is better to refer to them as "wind-deposited material."

Also important but not generally recognized as a distinctive deposit is dust, which is carried for long distances and deposited in small increments on a large part of the world. Dust can circle the earth in the upper atmosphere. Dust particles are mostly clay and very fine silt and may be deposited dry or be in precipitation. The accumulated deposits are large in some places. An immense amount of dust has been distributed widely throughout the ages. The most likely sources at present are the drier regions of the world. Large amounts of dust may have been distributed worldwide during and immediately following the glacial periods.

Dust is an important factor affecting soils in some places. It is the apparent source of the unexpected fertility of some old, highly leached soils in the path of wind that blows from extensive deserts some hundreds of kilometers distant. It explains unexpected micronutrient distribution in some places. Besides dust, fixed nitrogen, sulfur, calcium, magnesium, sodium, potassium, and other elements from the atmosphere are deposited on the soil in varying amounts in solution in precipitation.

Material moved and deposited by glacial processes

Several terms are used for material that has been moved and deposited by glacial processes. Glacial drift consists of all of the material picked up, mixed, disintegrated, transported, and deposited by glacial ice or by water from melting glaciers. In many places glacial drift is covered by a mantle of loess. Deep mantles of loess are usually easily recognized, but very thin mantles may be so altered by soil-building forces that they can scarcely be differentiated from the underlying modified drift.

Glacial till.—This is that part of the glacial drift deposited directly by the ice with little or no transportation by water. It is generally an unstratified, heterogeneous mixture of clay, silt, sand, gravel, and sometimes boulders. Some of the mixture settled out as the ice melted with very little washing by water, and some was overridden by the glacier and is compacted and unsorted. Till may be found in ground moraines, terminal moraines, medial moraines, and lateral moraines. In many places it is important to differentiate between the tills of the several glaciations. Commonly, the tills underlie one another and may be separated by other deposits or old, weathered surfaces. Many deposits of glacial till were later eroded by the wave action in glacial lakes. The upper part of such wave-cut till may have a high percentage of rock fragments.

Glacial till ranges widely in texture, chemical composition, and the degree of weathering that followed its deposition. Much till is calcareous, but an important part is noncalcareous because no carbonate rocks contributed to the material or because subsequent leaching and chemical weathering have removed the carbonates.

Glaciofluvial deposits.—These deposits are material produced by glaciers and carried, sorted, and deposited by water that originated mainly from melting glacial ice. Glacial outwash is a broad term for material swept out, sorted, and deposited beyond the glacial ice front by streams of melt water. Commonly, this outwash is in the form of plains, valley trains, or deltas in old glacial lakes. The valley trains of outwash may extend far beyond the farthest advance of the ice. Near moraines, poorly sorted glaciofluvial material may form kames, eskers, and crevasse fills.

Glacial beach deposits.—These consist of rock fragments and sand. They mark the beach lines of former glacial lakes. Depending on the character of the original drift, beach deposits may be sandy, gravelly, cobbly, or stony.

Glaciolacustrine deposits.—These deposits are derived from glaciers but were reworked and laid down in glacial lakes. They range from fine clay to sand. Many of them are stratified or varved. A varve consists of the deposition for a calendar year. The finer portion reflects slower deposition during the cold season and the coarser portion deposition during the warmer season when runoff is greater.

Good examples of all of the glacial materials and forms described in the preceding paragraphs can be found. In many places, however, it is not easy to distinguish definitely among the kinds of drift on the basis of mode of origin and landform. For example, pitted outwash plains can scarcely be distinguished from sandy till in terminal moraines. Distinguishing between wave-cut till and lacustrine material is often difficult. The names themselves connote only a little about the actual characteristics of the parent material.

Material moved and deposited by gravity

Colluvium is poorly sorted debris that has accumulated at the base of slopes, in depressions, or along small streams through gravity, soil creep, and local wash. It consists largely of material that has rolled, slid or fallen down the slope under the influence of gravity. Accumulations of rock fragments are called talus. The rock fragments in colluvium are usually angular, in contrast to the rounded, water-worn cobbles and stones in alluvium and glacial outwash.

Organic Material

Organic material accumulates in wet places where it is deposited more rapidly than it decomposes. These deposits are called peat. This peat in turn may become parent material for soils. The principal general kinds of peat, according to origin are:

Sedimentary peat. the remains mostly of floating aquatic plants, such as algae, and the remains and fecal material of aquatic animals, including coprogenous earth.

Moss peat. the remains of mosses, including Sphagnum.

Herbaceous peat. the remains of sedges, reeds, cattails, and other herbaceous plants.

Woody peat. the remains of trees, shrubs, and other woody plants.

Many deposits of organic material are mixtures of peat. Some organic soils formed in alternating layers of different kinds of peat. In places peat is mixed with deposits of mineral alluvium and/or volcanic ash. Some organic soils contain layers that are largely or entirely mineral material.

In describing organic soils, the material is called peat (fibric) if virtually all of the organic remains are sufficiently fresh and intact to permit identification of plant forms. It is called muck (sapric) if virtually all of the material has undergone sufficient decomposition to limit recognition of the plant parts. It is called mucky peat (hemic) if a significant part of the material can be recognized and a significant part cannot.

Descriptions of organic material should include the origin and the botanical composition of the material to the extent that these can be reasonably inferred.

Contrasting Materials

Changes with depth that are not primarily related to pedogenesis but rather to geological processes are contrasting soil materials if they are sufficient to affect use and management. The term discontinuity is applied to certain kinds of contrasting soil materials.

Unconsolidated contrasting soil material may differ in pore-size distribution, particle-size distribution, mineralogy, bulk density, or other properties. Some of the differences may not be readily observable in the field. Some deposits are clearly stratified, such as some lake sediments and glacial outwash, and the discontinuities may be sharply defined.

Contrasting materials can be confused with the effects of soil formation. Silt content may decrease regularly with depth in soils presumed to have formed in glacial till. The higher silt content in the upper part of these soils can be explained by factors other than soil formation. In some of these soils, small amounts of eolian material may have been deposited on the surface over the centuries and mixed by insects and rodents with the underlying glacial till. In others, the silt distribution reflects water sorting.

Inferences about contrasting properties inherited from differing layers of geologic material may be noted when the soil is described. Generally, each identifiable layer that differs clearly in properties from adjacent layers is recognized as a subhorizon. Whether it is recognized as a discontinuity or not depends on the degree of contrast with overlying and underlying layers and the thickness. For many soils the properties inherited from even sharply contrasting layers are not consistent from place to place and are described in general terms. The C layer of a soil in stratified lake sediments, for example, might be described as follows: "consists of layers of silt and clay, 1 to 20 cm thick; the aggregate thickness of layers of silt and that of the layers of clay are in a ratio of about 4 to 1; material is about 80 percent silt."

Erosion

Erosion is the detachment and movement of soil material. The process may be natural or accelerated by human activity. Depending on the local landscape and weather conditions, erosion may be very slow or very rapid.

Natural erosion has sculptured landforms on the uplands and built landforms on the lowlands. Its rate and distribution in time controls the age of land surfaces and many of the internal properties of soils on the surfaces. The formation of Channel Scablands in the state of Washington is an example of extremely rapid natural, or geologic, erosion. The broad, nearly level interstream divides on the Coastal Plain of the Southeastern United States are examples of areas with very slow or no natural erosion.

Landscapes and their soils are evaluated from the perspective of their natural erosional history. Buried soils, stone lines, deposits of wind-blown material, and other evidence that material has been moved and redeposited is helpful in understanding natural erosion history. Thick weathered zones that developed under earlier climatic conditions may have been exposed to become the material in which new soils formed. In landscapes of the most recently glaciated areas, the consequences of natural erosion, or lack of it, are less obvious than where the surface and the landscape are of an early Pleistocene or even Tertiary age. Even on the landscapes of most recent glaciation, however, postglacial natural erosion may have redistributed soil materials on the local landscape. Natural erosion is an important process that affects soil formation and, like man-induced erosion, may remove all or part of soils formed in the natural landscape.

Accelerated erosion is largely the consequence of human activity. The primary causes are tillage, grazing, and cutting of timber.

The rate of erosion can be increased by activities other than those of humans. Fire that destroys vegetation and triggers erosion has the same effect. The spectacular episodes of erosion, such as the soil blowing on the Great Plains of the Central United States in the 1930s, have not all been due to human habitation. Frequent dust storms were recorded on the Great Plains before the region became a grain-producing area. "Natural" erosion is not easily distinguished from "accelerated" erosion on every soil. A distinction can be made by studying and understanding the sequence of sediments and surfaces on the local landscape, as well as by studying soil properties.

Climate (factor 2)

- The most important factor acting on parent material!

- Direct effects influence:
  - Rainfall quantity, intensity and distribution which *influences*
    - depth of leaching
    - amount of water available for reactions

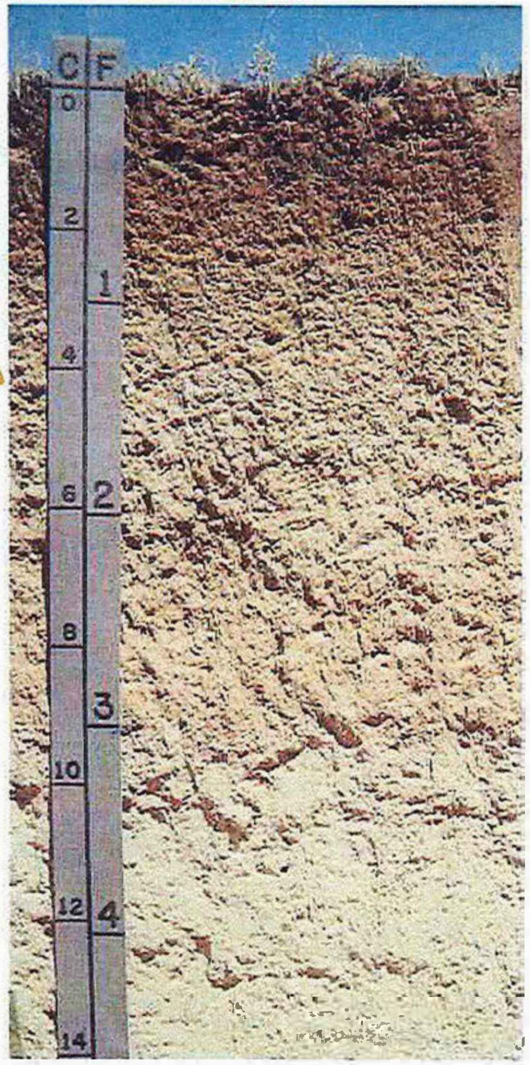
  - Temperature *influences*
    - degree of heating, freezing

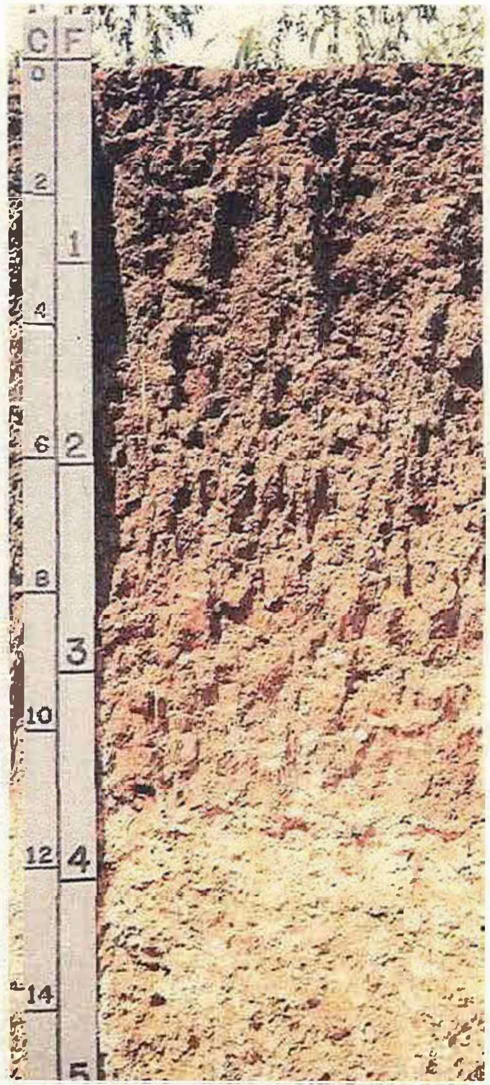
Climate (cont.)

- Indirect effects influence:
  - Type and abundance of living things which *influences*
    - organic matter supply
  - Rate of chemical reactions which *influences*
    - degree of weathering and leaching
    - accumulation of organic matter

Influence of Climate on Soil Development

•Dry Climate (warm or cold temperatures)





•Moist Climate (Note deeper soil development)

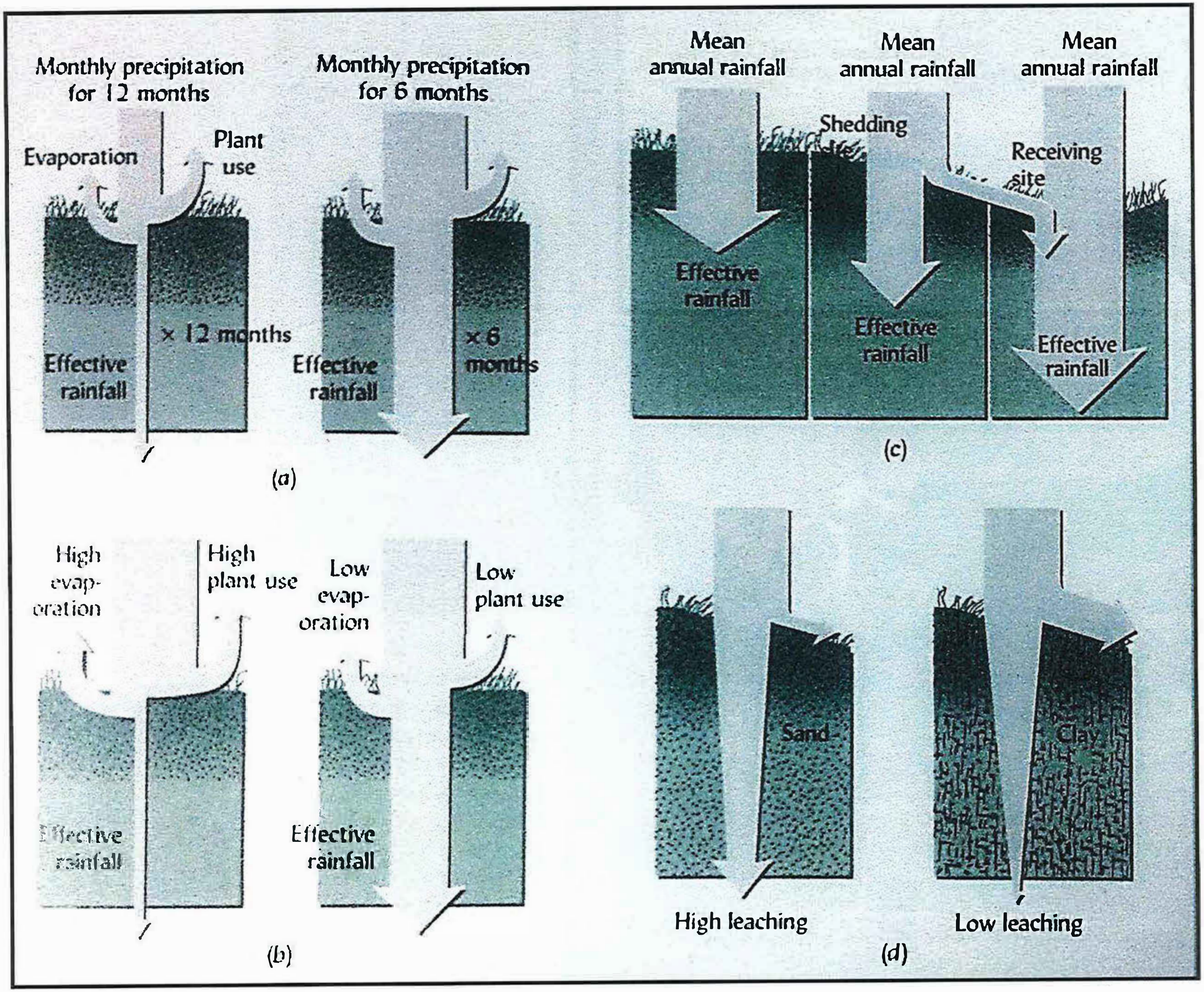
To fully promote soil development, water must not only enter the profile and participate in weathering reactions; it must percolate thru the soil and and translocate soluble weathering products.

- a) **Seasonal distribution of precipitation:** rain distributed evenly thru the year is less likely to cause erosion or soil leaching as same amount falling in a 6 month rainy season.

- b) **Temperature and evaporation:** In a hot climate evaporation from soils and vegetation is much higher than in a cool climate; therefore in a hot climate less precipitation available for percolation and leaching as compared to cool climate.

- c) **Topography:** Water falling on a steep slope will run downhill so rapidly only a small portion will enter soil. Level or concave sites will experience more percolation and leaching than sloping sites. Effective rainfall greatest on concave site, least on sloping site.

- d) **Permeability:** more water will infiltrate through a coarse, sandy profile than a tight, clayey one; therefore sandy profile will experience greater effective precipitation, and potentially more soil development.



Monthly precipitation for 12 months
Evaporation
Plant use
× 12 months
Effective rainfall
Monthly precipitation for 6 months
× 6 months
Effective rainfall
(a)
Mean annual rainfall
Mean annual rainfall
Mean annual rainfall
Shedding
Receiving site
Effective rainfall
Effective rainfall
Effective rainfall
(c)
High evap-oration
High plant use
Effective rainfall
Low evap-oration
Low plant use
Effective rainfall
(b)
Sand
Clay
High leaching
Low leaching
(d)

Biota or Living Organisms (factor 3)

- More vegetation = less erosion
  - soils can develop more deeply

- Notice the effect of Climate on vegetation type and amount

Biota or Living Organisms

- Bacteria and higher plants may secrete substances which bind soil particles together
- Burrowing animals carry and mix soil materials
  - earthworms: aerate soil, enhance availability of some nutrients, increase stability of aggregates

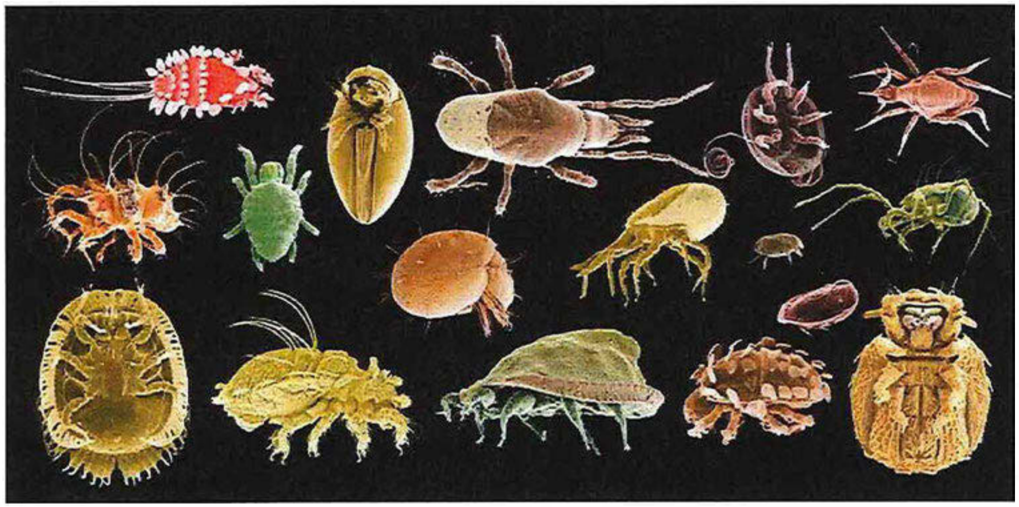
Biota or Living Organisms

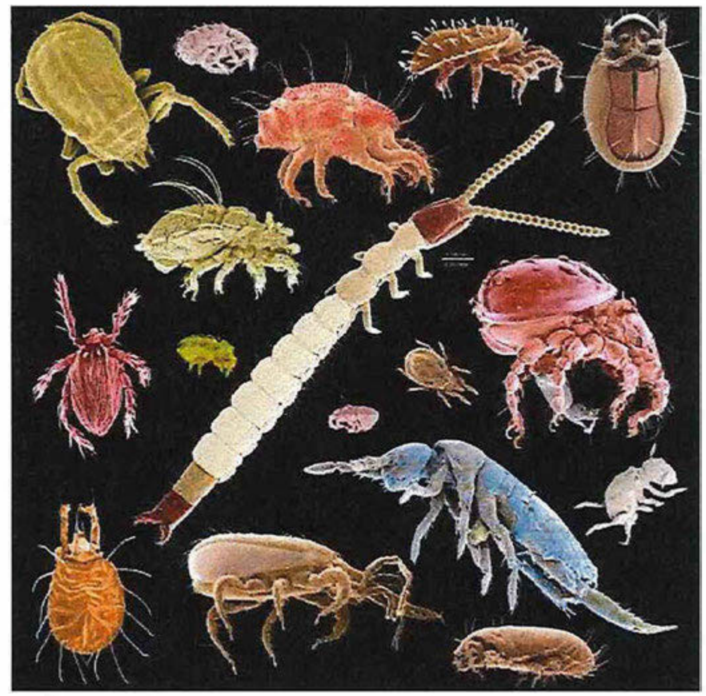
- The type of vegetation has an effect on soil development
  - Trees:
    - more likely to be acid soils
    - less organic matter produced (mostly leaf litter)
    - fungi needed to break down litter
  - Grasses: less acid soils, more organic matter (more roots and tops), N-fixing bacteria abundant

Biota or Living Organisms

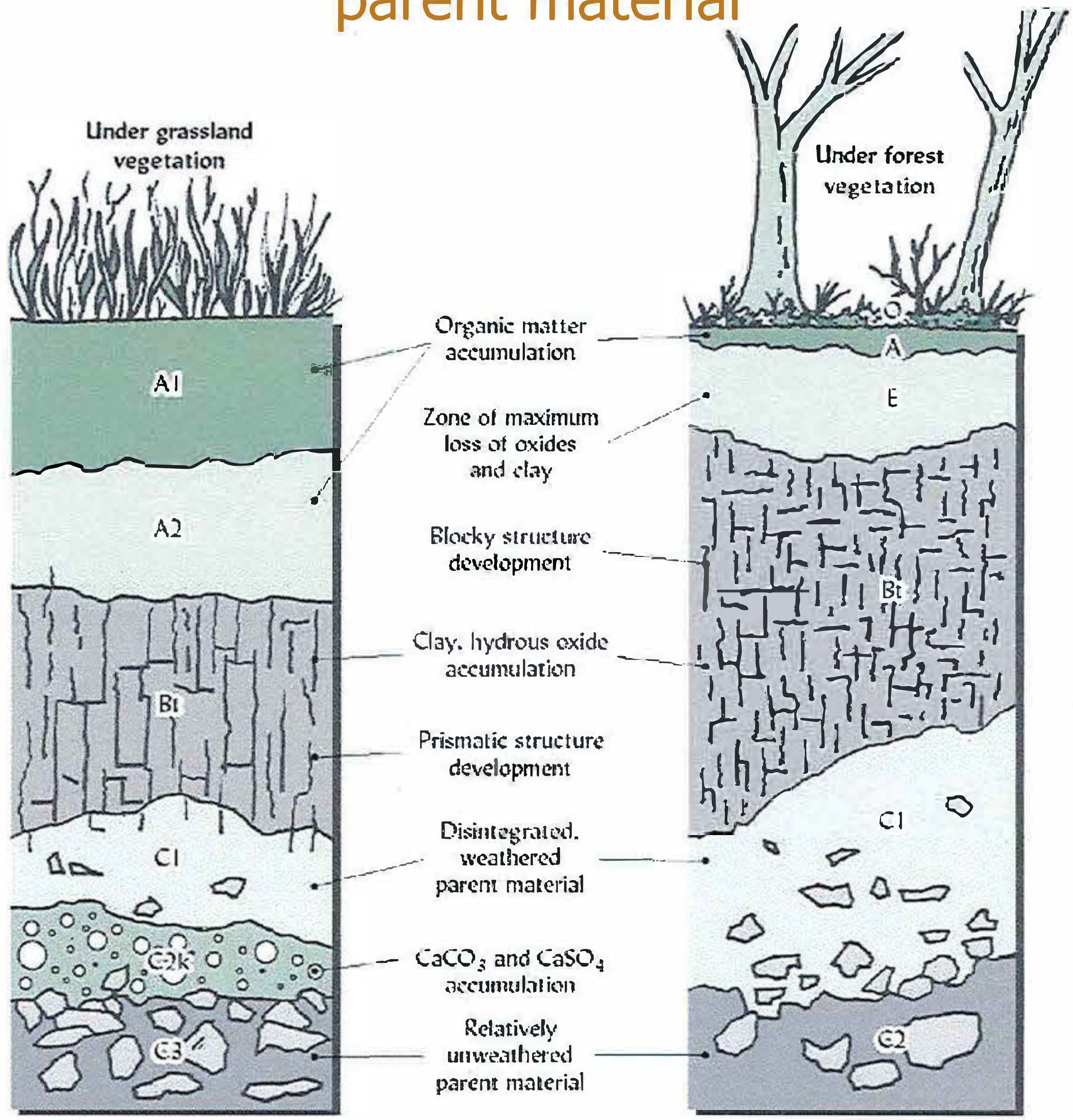
- The type of vegetation has an effect on soil development continued…
  - Grasses:
    - less likely to be acid soils
    - much more organic matter produced (more roots and tops) as compared to trees
    - Nitrogen-fixing bacteria abundant

Soil Organisms

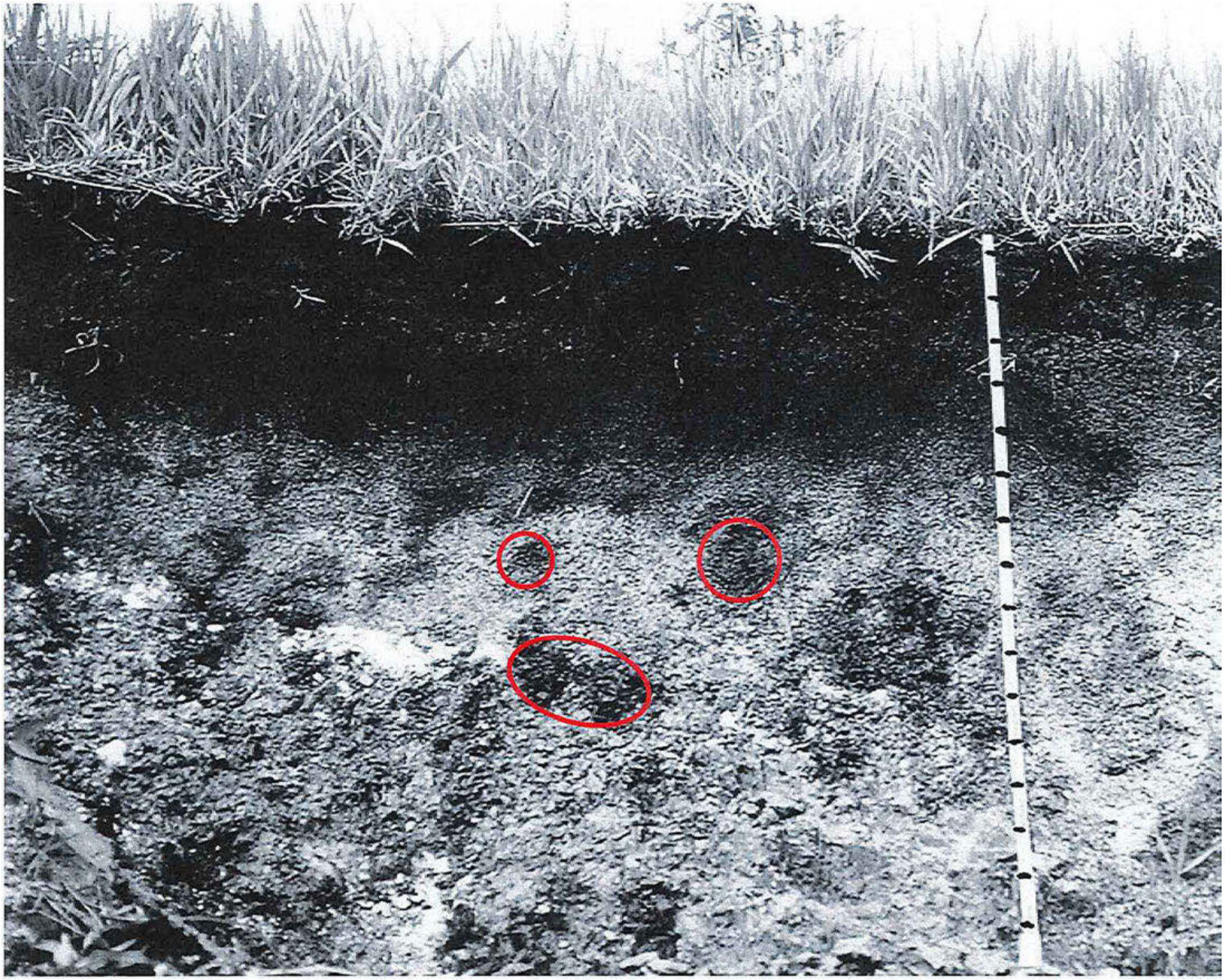




Influence of vegetation type on soil development in a given parent material



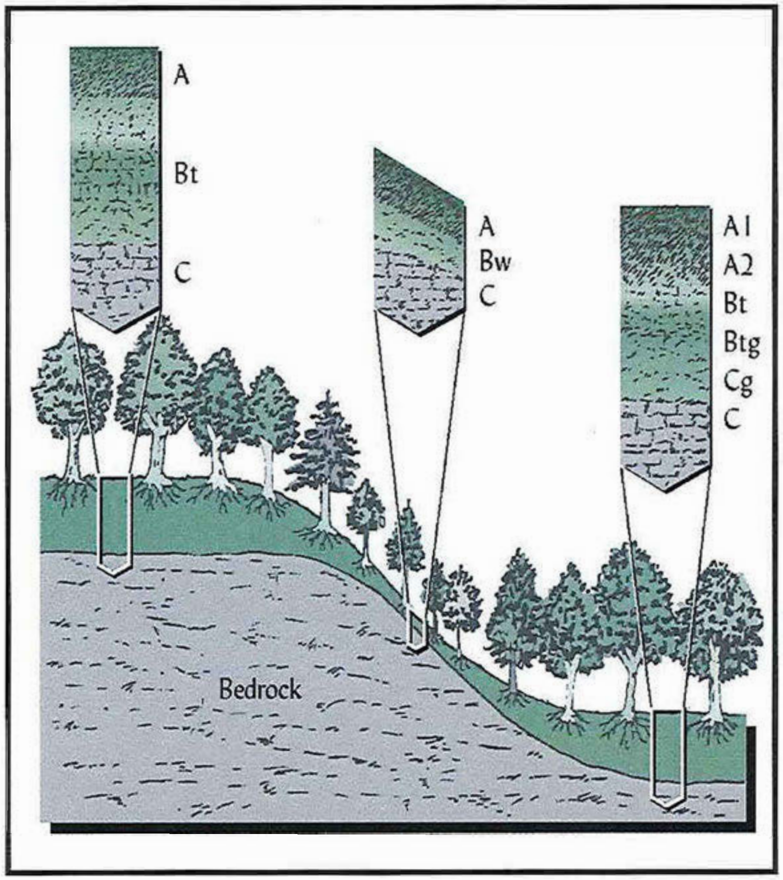
Translocation of soil material in animal burrows

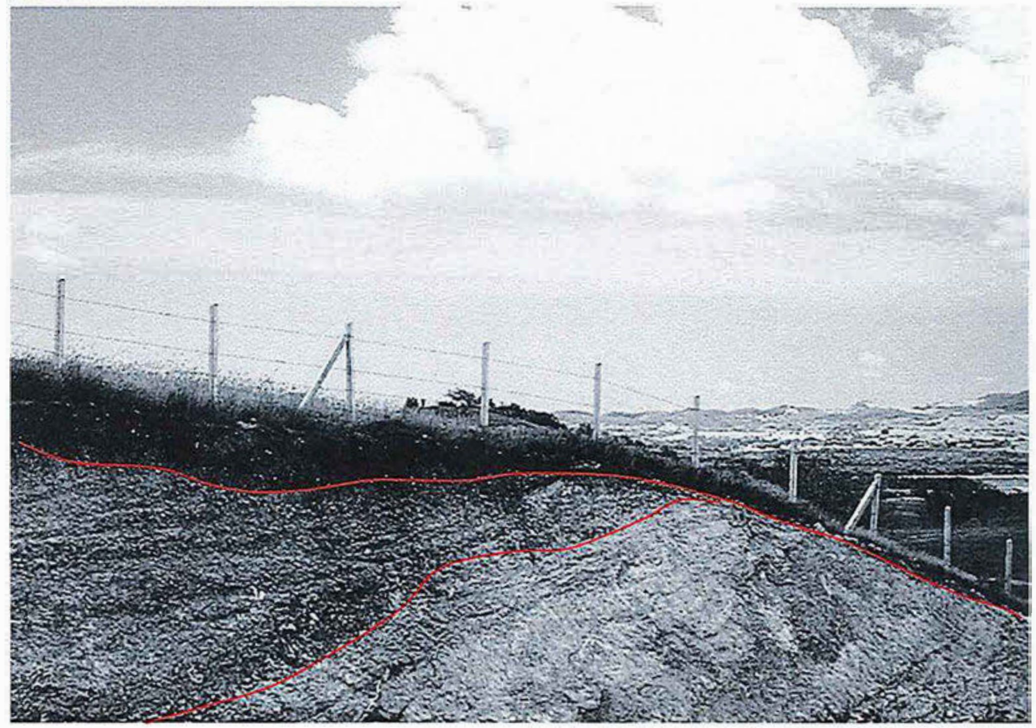


Topography (factor 4)

- Refers to configuration of the land surface
  - described in terms of slope, elevation differences, and landscape position
  - slope affects degree of erosion and deposition
    - steep slopes: ⬆ runoff, ⬆ erosion, ⬇ infiltration
      - shallow, poorly developed soil is formed
    - swales: ⬇ runoff, ⬇ erosion, ⬆ infiltration
      - deeper, well developed soil is formed
    - depressions:
      - wetland soils or very deep soils may form

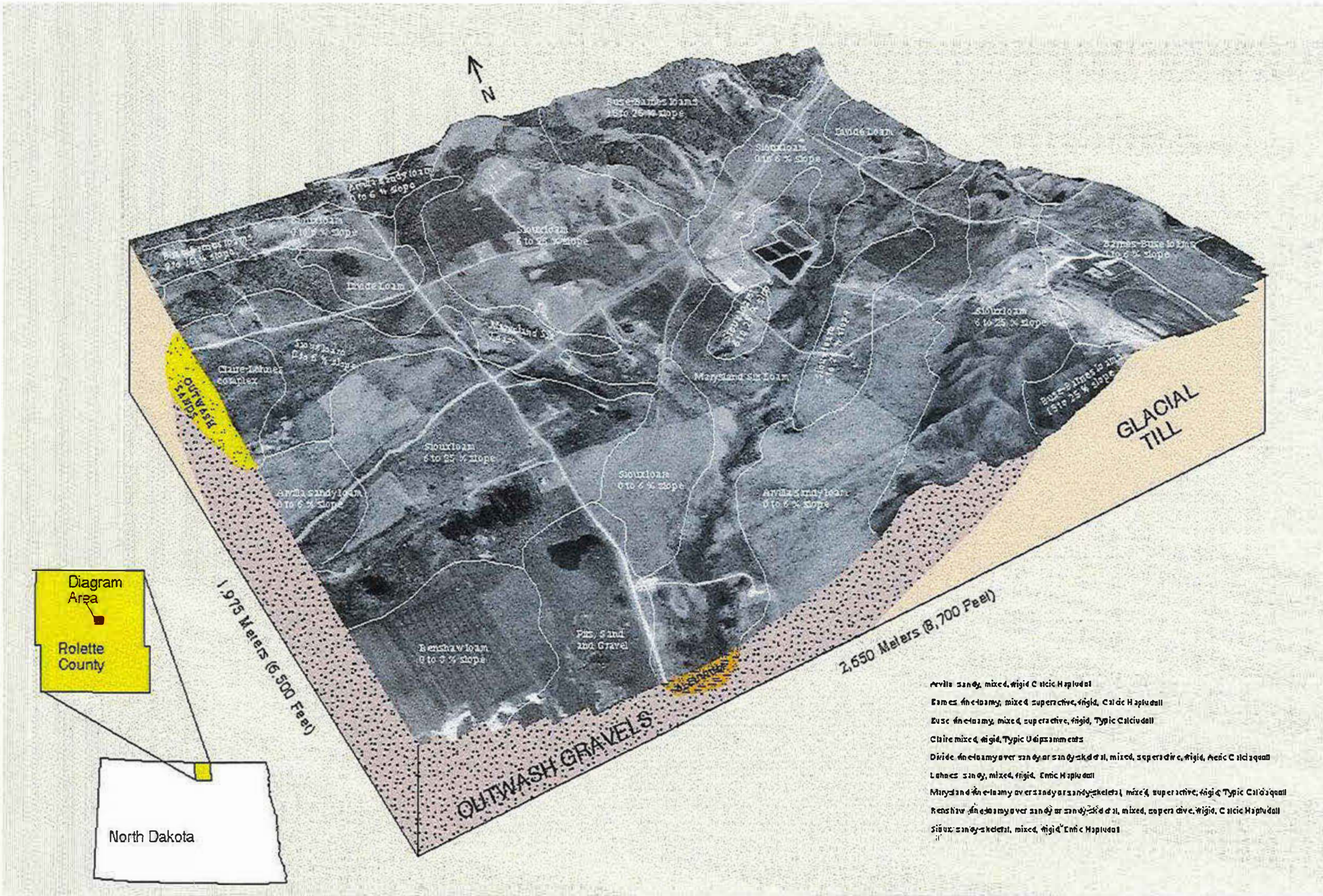
Influence of topography on soil depth





Catena: a group of soils along a slope formed in the same PM Arent aterial

Influence of Landscape Position on Soil Development



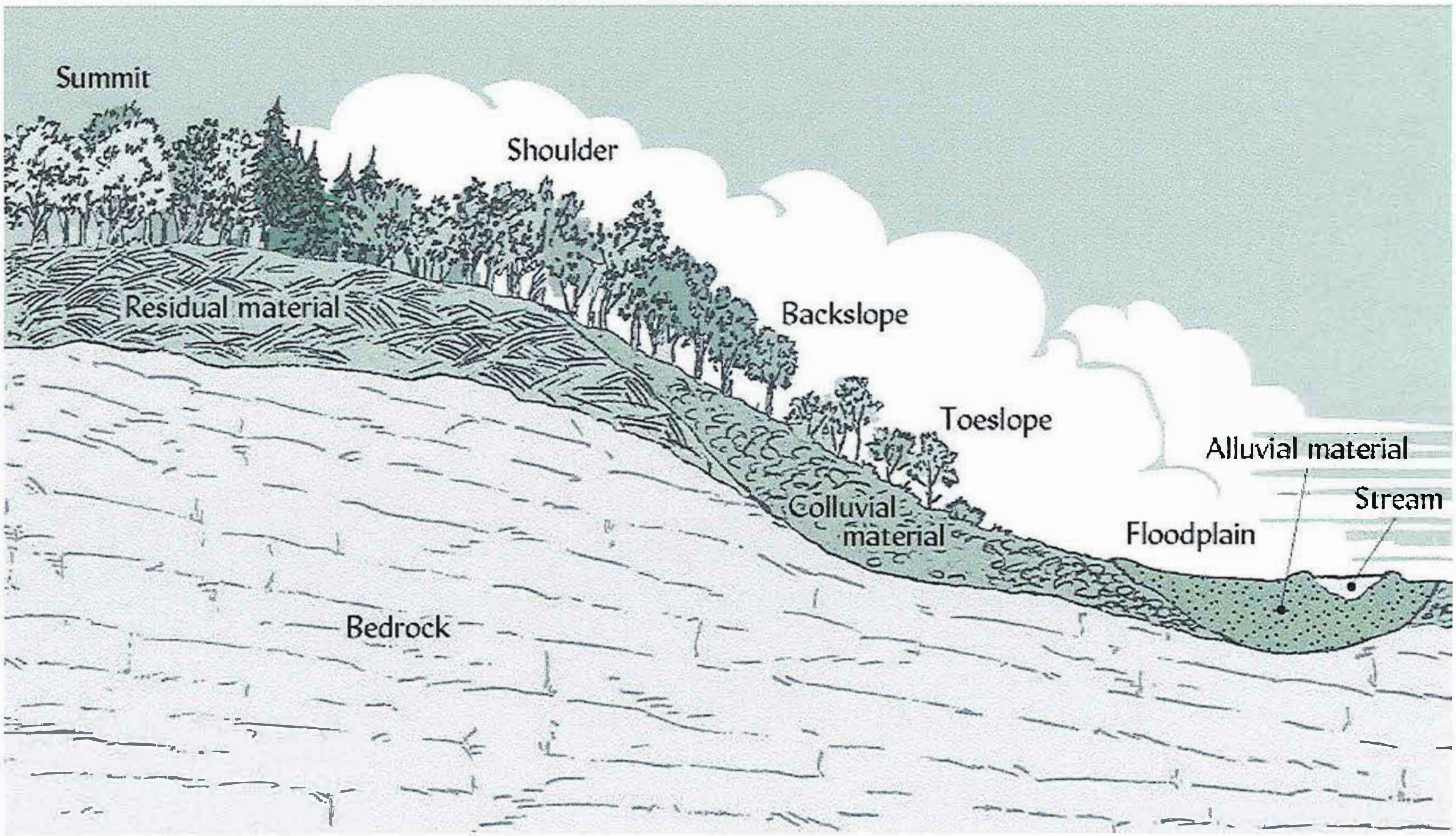
Topography (cont.)

- Topography and microclimate effects
  - South-facing (S aspect) slopes warmer
    - less available moisture
    - less vegetation and OM…therefore
    - less weathering and soil development

  - North-facing (N aspect) slopes cooler
    - more available moisture
    - more vegetation and OM…therefore
    - more weathering and soil development

N/S slope aspect effect on soil development

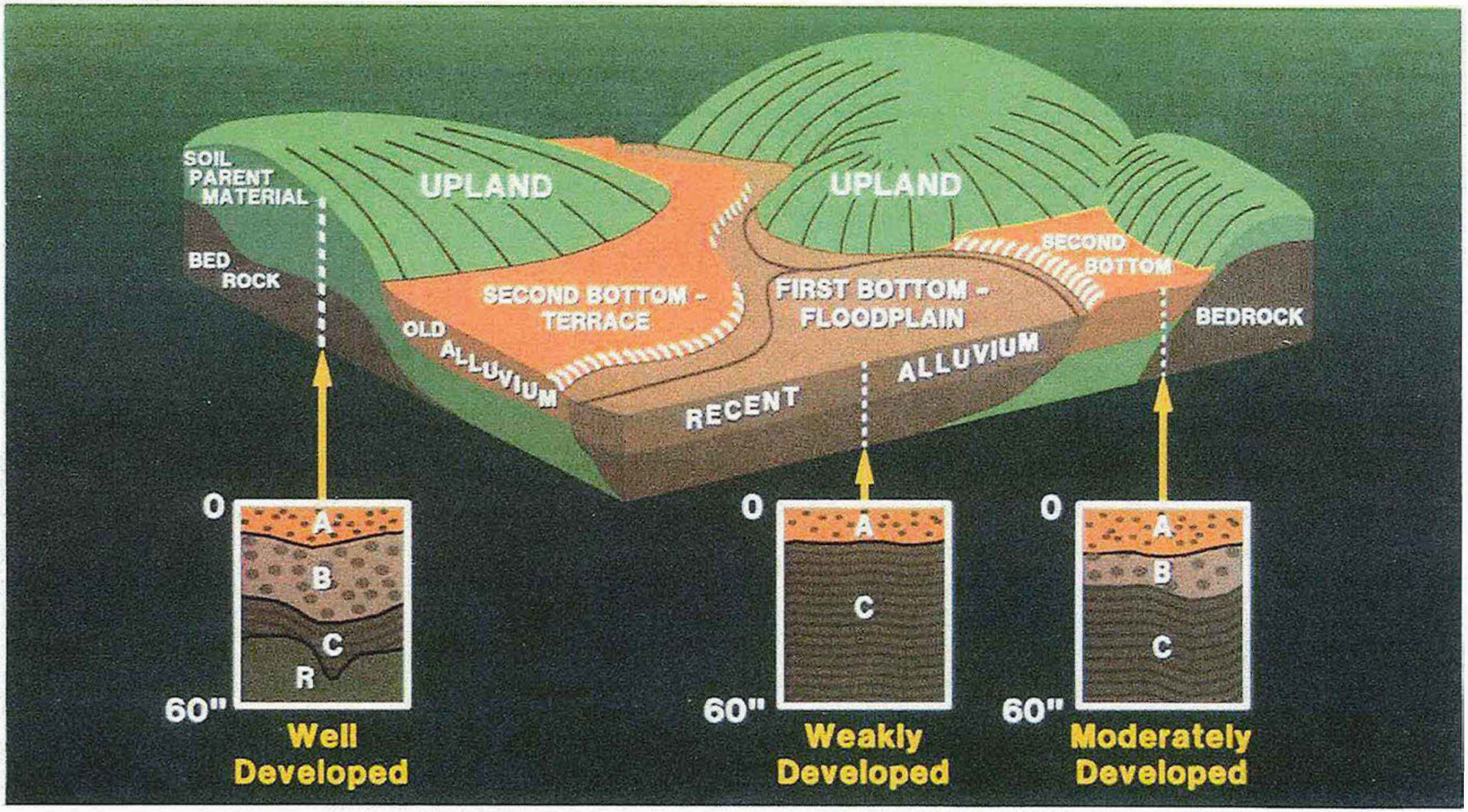
Interaction of topography and parent material as factors of soil formation



Time (factor 5)

- Influences:
  - vegetation
  - topography
  - degree of weathering
  - prevailing climate
- Older soils have a greater degree of development than younger ones

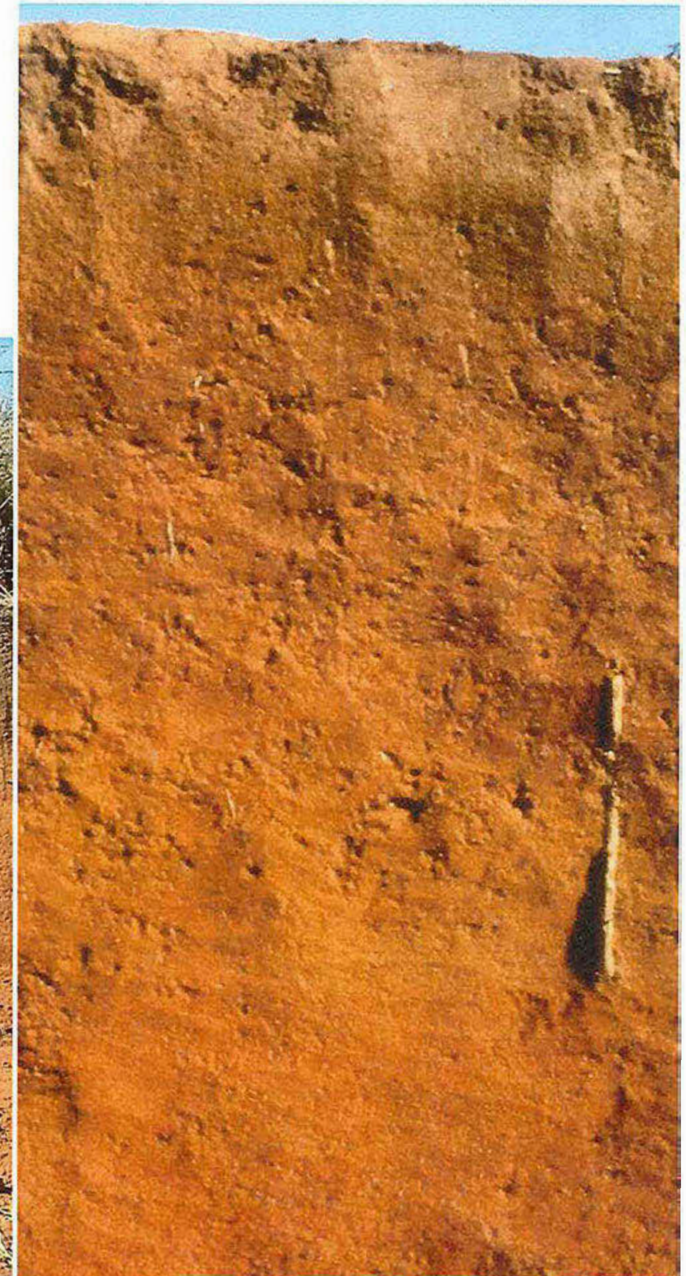
Influence of Time on Soil Development



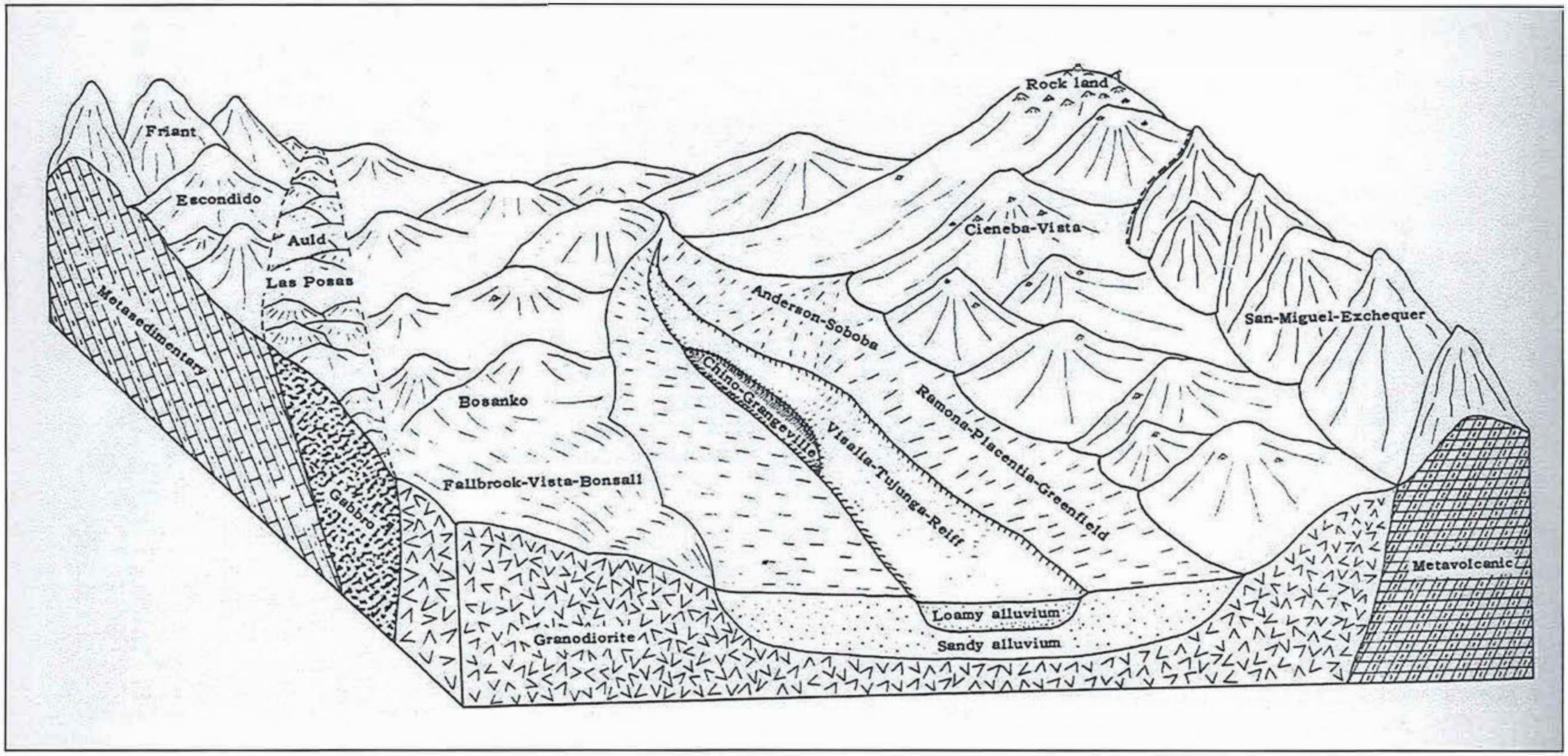
Time (cont.)

- As soils become very old they develop:
  - low fertility
  - stable (non-reactive) chemistry
  - restrictive layers (laterite)
  - may be composed of mostly Al and Fe oxides (giving very red color)

Soils dominated by Al and Fe oxides



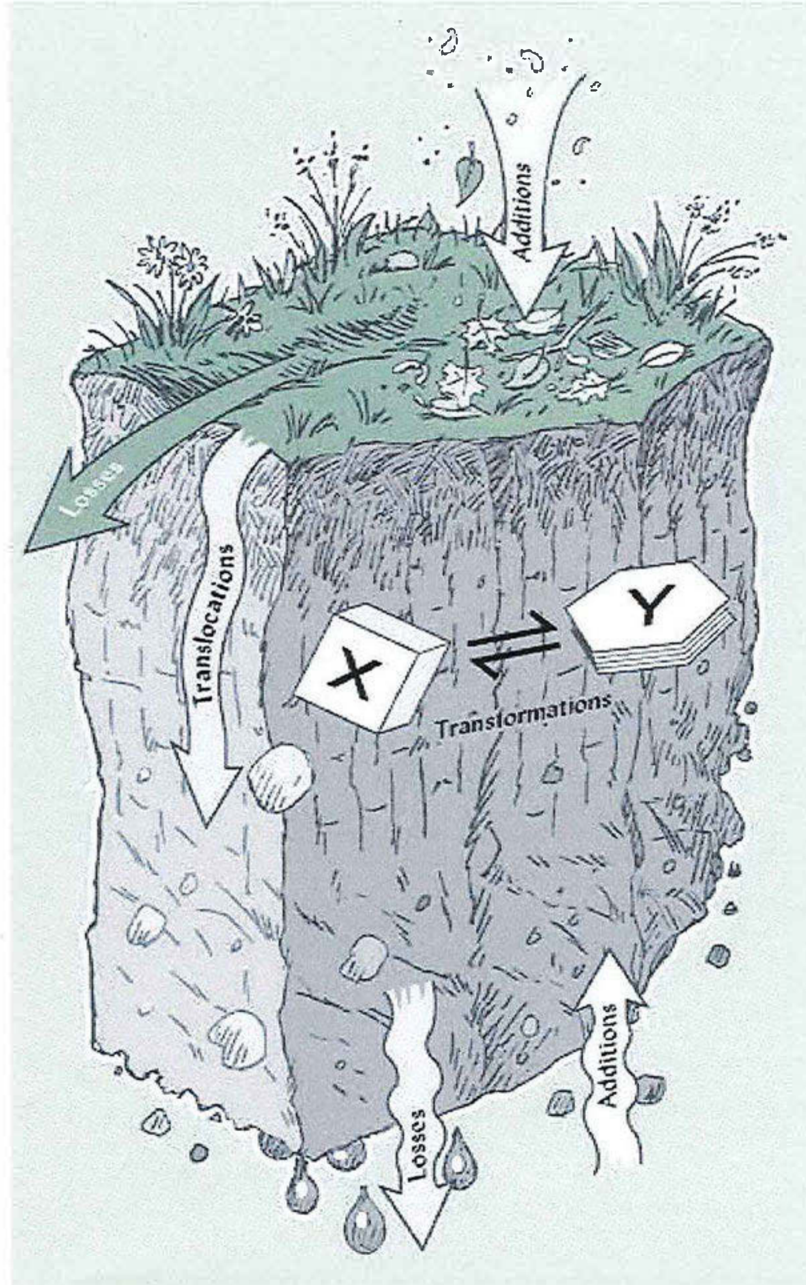
The soil-forming factors create soils across a landscape in an often complex but rational pattern.



Processes of soil formation

- Transformations: weathering, synthesis and recombination of new compounds
- Translocations: movement of clays, dissolved salts, organic substances by water or organisms
- Additions: OM from roots, dust from air
- Losses: leaching to groundwater, erosion of surface, evaporation/plant use of water

Additions, losses, translocations, and transformations as fundamental processes driving soil development



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Landforms of the Basin & Range Province Defined for Soil Survey

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Dale W. Bohmont, Dean and Director

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SUMMARY

The classification of intermontane-basin landforms presented here was designed to help locate both soil associations and individual soils in a landscape. It is based on morphogenetic affinities of landforms and on their physical scales relative to individual soils. The landforms are illustrated with line drawings which accentuate their diagnostic features. Most of the names were selected from the literature for familiarity. Some were coined and a glossary is appended.

Intermontane basins are differentiated as bolsons and semi-bolsons by their internal or external drainage. These very similar basins are divided into mountain, piedmont-slope, and basin-floor major physiographic parts. Mountain and hill landforms cannot be classified further at present, but *ad hoc* description of their erosional slopes is explained. The major physiographic parts are divided into major landforms: mountain-valley fans, ballenas, alluvial fans, fan piedmont, fan skirt, alluvial flat, and playa or axial-stream floodplain. These major landforms are then described by their component landforms, or the erosional remnants and constructional additions, which along with relict areas now compose the original area of a major landform and accord with many individual soils. Fan remnants, inset fans, and fan aprons are examples of component landforms. Landform elements, or genetically distinctive parts of component landforms, such as summit and sideslope, are identified next. Slope components of the erosional-sideslope landform element are the final subdivision. Classes of the latter two categories accord with most individual soils whose physiographic position is not precisely identified by the more general terms.

Since effective use of landform analysis in soil surveys requires understanding the vagaries of both landform nomenclature and soil mapping, the narrative starts with a brief historical explanation of each. Landform analysis merges with recognition of geomorphic surfaces, a basic tool for understanding soil patterns and genesis. A tool that must be narrowly defined, however, to serve soil studies. Those requirements are discussed briefly.

Range scientists, geographers, archaeologists, and geologists may find this landform classification useful for field work. They also may wish to turn directly to the section on *Basin and Range Landscapes*.

Cover Photo: A view of the fan piedmont and alluvial fans below the Quinn Canyon Range on the east side of Railroad Valley, Nevada. One large alluvial fan issues from Deep Creek, behind and immediately left of the dark trees at a ranch headquarters in the middleground. Other small alluvial fans issue from minor drainages of the mountain front to the right of the photo. The alluvial fan from Deep Creek flares out onto the fan piedmont about half a mile behind the ranch headquarters. Though not visible from the distance of this photo, this large alluvial fan is comprised of one area of prominent erosional fan remnants and another, larger area of only somewhat dissected, relict fan surface. A barely visible light streak extending out from the mouth of Deep Creek is the north wall of a deep fanhead trench cut across the alluvial fan and occupied by an inset fan. The fan piedmont, which extends from the foreground to the middleground, is a largely relict fan surface with some younger fan aprons that are not visible. To the far right, a short belt of digitate ballenas sets below minor drainages of the mountain front. The fan piedmont is about 5,000 feet elevation in the immediate foreground. The apex of the Deep Creek alluvial fan is at about 6,000 feet, some five miles distant, and the Quinn Canyon Range rises to peaks of 10,000 feet elevation.

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LANDFORMS AND SOIL SURVEY

The traditional, detailed soil surveys could ignore landform description, but the reconnaissance soil surveys now being made through the western United States demand effective landform identification to help establish soil location. Both types of surveys have as their primary purposes (1) identifying *kinds* of soils and (2) showing their *locations*. Names from classifications identify kind, whereas maps should establish location. During the years when most soil surveys were detailed, the boundary of each delineation[1] of the most commonly-used map unit automatically showed the location of an *individual* soil in the landscape. This kind of map unit has only one soil component per delineation and is now called a *soil consociation*. At that earlier time, therefore, interest in locating soils concentrated on cartographic accuracy and map utility in the field. Aerialphoto maps replaced topographic base maps in the early 1940's because the drainageways, trails, fields, and vegetation they revealed were a much more effective control for finding soil boundaries in the field both during and after mapping. In comparison, reconnaissance soil surveys, such as those now called Order 3 and 4 surveys[2], have built-in problems for locating individual soils that are not noticed for most detailed, or Order 2, soil surveys.

Soil location is somewhat equivocal in reconnaissance soil surveys because their maps are generalized by using *soil association* map units and by reducing map scale. Soil associations have two or more component soils per delineation and several bodies of each component are apt to occur in each delineation. Their *individual locations*, therefore, are not shown by boundaries. Small map scale results in the delineations representing very large landscape areas[3] and exaggerates the problems. These generalized maps are popular for planning extensive land uses of large areas. They may also be used for field operations that still require locating individual soils.

Since soil patterns so commonly coincide with landforms, physiographic position, i.e., position relative to landforms, can be used to describe where individual soils may be found within delineations of a soil association. But, soil surveyors have had difficulty describing physiographic positions even though they have used landforms as one clue for mapping soils since the 1890's. The problem is partly one of unfamiliarity with landform terminology and partly that *utilitarian* landform concepts bear little relation to genetic soil patterns. Furthermore, even *morphogenetic* landform concepts that relate to soil patterns have been used for different landforms thus confusing their meaning. Another factor is the expansible physical scale with which landform designations have been applied in the geological and geographic studies from which they have been taken for use in soil survey.

This bulletin presents a hierarchical and morphogenetic landform classification for the intermontane basins of the western United States that is tied to the physical scale of soils. Utilitarian and morphogenetic landform concepts and their applicability to soil surveys are discussed. Means for *ad hoc* landform descriptions of hills and mountains are suggested. And, since landform recognition merges with the concept of the geomorphic surface that is so valuable for mapping soils, this concept is briefly investigated.

Landforms and Landscapes

Geographers define a *landscape* as all those features the eye perceives in a sweeping out-of-doors view: the vegetation, buildings, roads, fields, and those multiple topographic features, or landforms—such as hills, valleys, and plains—that so often are related to land use. A *landform* is a three-dimensional part of the general land surface which is distinctive and recognizable because it has some *significance* to people and *repeats* across the landscape in a fairly *consistent position* with respect to surrounding landforms. Thus, hills are elevated masses that stand above, and have sideslopes steeper than the surrounding plains or valley floors. Or, a stream terrace is a bench that sets within sloping valley walls and above a paralleling floodplain. Some landforms are composed of distinctive materials. Other landforms, such as hills and plains, may be underlain by a variety of rocks, alluvium, loess, or other materials.

When geologists view a landscape, they emphasize landforms, particularly those to which they can attach an understanding of formation by erosion or deposition. Soil surveyors share both geographers' and geologists' interests, but the genetic implications of the landforms take priority. They suggest those differences in soil age, parent material, and drainage that largely determine soil patterns, and also can be used to design soil-association map units that fit easily recognizable parts of large landscapes and have predictable soil patterns.

Landforms are recognized because they have some special significance. Since various people will view the same topographic feature with different interests, it is not surprising they will use various names for the feature, or set its boundaries at different locations in their mind's eye. Hills, mountains, valleys, and plains are *utilitarian* identifications that suggest ease of travel, possible water

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[1] A *delineation* is an area *on a map* enclosed by a boundary. A *map unit* is comprised of one to many delineations that show locations in a landscape where there are the same kind or kinds of soils. One or more *component soils* occupy the majority of each delineation of a map unit and are formally identified in the map unit name or description. Normally, there are additional *inclusions* of similar or contrasting soils that may or may not be in any particular delineation or mentioned in the map unit description. Soil mapping terminology and kinds of soil map units are defined in Appendix I, Table 2.

[2] The different *orders* of soil surveys, which identify kinds of surveys and mapping intensity, are described in Appendix I.

[3] Mapping scales and the resultant areas represented by minimum size delineations are listed in Appendix II.

sources, or field locations. Utilitarian identifications carry few implications for soil occurrence.

Floodplains, stream terraces, alluvial fans, and playas are *morphogenetic* identifications that not only have utilitarian implications, but also indicate a particular topographic form and suggest the mode of formation, kind of material, and drainage. By its relation to other landforms, a landform may even suggest soil age. Morphogenetic identifications are more useful for soil surveys, but unfortunately not all landforms have morphogenetic names, or the names have been used with various meanings. For this bulletin, morphogenetic names for landforms of intermontane basins have been selected largely from the geological literature and some have been redefined, a few have been coined, and all these are presented in a morphogenetic hierarchy. Equally useful terms for hills and mountains are lacking, but some ways of identifying their features are suggested.

Soil Mapping and Landforms

Soil surveyors sometimes are asked how many samples they take during mapping. It is difficult to explain that pits are usually dug only to confirm a prediction of the kind of soil that should occur in a landscape parcel and that mapping is based mostly on things seen. A metaphor helps: If one were asked, for some strange reason, to map the amount, distribution, and type of roots over 100,000 acres of range and woodland, how might it be done? The roots are out-of-sight, hidden. Certainly one wouldn't dig up every plant—that would destroy the vegetation and be prohibitively expensive. Many people quickly and correctly answer, "why, I would examine the roots of the common plants, and then use the plants I can see to make the map." A soil surveyor likewise makes local correlations between visible landscape features and the soils "hidden" beneath the land surface. Soils are mapped largely by what can be *seen*—landforms, vegetation, rocks, etc.—and what we have learned those visible features *imply* about the parent materials, drainage, and ages of land surfaces that control soil patterns. These genetic factors, along with climate and vegetation, allow mapping soils by prediction with pits used largely for confirmation.

Why Identify Landforms by Name?

Soil surveyors certainly do not have to name landforms to see and correlate them with soils. But most people see those things they can name more sharply. Also, identifying landforms by name greatly speeds training novices and helps readers of soil surveys visualize where the soils occur. Three more benefits may be obtained from explicit identification: First, if one wittingly thinks about a landform, he may be able to predict the particle sizes, stratification, depth to bedrock, and in certain situations, the mineralogy of the parent material it provides. Second, if the patterns of landforms are noted, they commonly suggest soil ages. A floodplain soil, for example, has to be younger than a soil on an adjacent stream terrace that stands above it. Therefore the soils are apt to differ. Such predictions facilitate soil mapping. Third, landform patterns are a powerful tool for designing and describing soil map units, if the landforms can be named.

Problems in Using Landforms for Soil Survey

Some familiar landform names do not differentiate the physiographic positions of associated soils that clearly occupy different positions. For example, very different soils with various ages are apt to occur on the same "alluvial fan". This happens because individual soils (polypedons[4]) are not necessarily, or even commonly, *coextensive* with landforms traditionally conceived. To continue the example, most large alluvial fans[5] are actually comprised of numerous remnants and recent small deposits of different ages. Each age of surface thus formed is apt to have its own kind of soil. In practice, the familiar concept, "alluvial fan", refers only to the gross topographic form, alluvial material, and gross position in the landscape. The *physical scale* at which alluvial fans and other familiar landforms are commonly recognized *is not the same scale at which soils occur* on the various-age alluvial deposits and erosion surfaces that comprise these *major landforms*. Other major landforms that ordinarily are much larger physical features than the bodies of soil that comprise their surfaces include the mountain-valley fans, fan piedmonts, alluvial flats, lake plains, and playas. All will be described later[5]. The hierarchical classification of the landforms in intermontane basins that is given here provides an at least a partial solution for this problem of scale.

A similar classification is not presently available for the hills and mountains which bound intermontane basins. Mountains are distinguished from hills on a strictly utilitarian basis of relief (i.e., mountains are greater than 1000 feet from base to summit, hills are less). Some simple, single-category distinctions are available for shape. They include buttes, mesas, hogbacks, cuestas, and domes, but these bear little relation to soil patterns. Rather, the positions of soils on hills are best described by slope components (e.g., crest, shoulder, backslope, footslope, toeslope) and by shape of the slopes. These slope components and shapes can be related to models of erosional slope development (discussed later) and provide genetic clues to soil occurrence.

The second problem was mentioned earlier: among the available landform concepts, some are utilitarian and some morphogenetic and they are not equally useful. Patently utilitarian names come from the common language. For example, plains are easier to cross on foot or in a wagon than hills, and mountains are tall barriers infrequently broken by "passes". Valley bottoms are places where water might be found, and a gully can be traversed more quickly than a canyon. Other landform names have had genetic meanings attached, or have been newly devised since the advent of geological understanding. These *morphogenetic* terms are the most useful to us

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[4]A *polypedon* is an individual body of soil identified at the soil-Series level of taxonomic generality. It is the real and smallest individual soil body that we classify, identify, and map. We may identify soil bodies at higher taxonomic levels, e.g., by soil Family or Subgroup, or cartographically generalize to try and fit large landform units, but the basic intellectual problem of coextensive physical scales is not alleviated.

[5]Many of the landform terms that are unfamiliar to the reader, and not yet defined, may be found in the Glossary.

since they imply form, genesis, and materials that with their relations to adjacent landforms, help us understand soil patterns. For example, floodplains are transversely nearly level. They are composed of size sorted, commonly stratified alluvium and they may have a shallow water table. Also they are younger than an adjacent stream terrace. Similarly, a simple alluvial fan has a straight or slightly concave slope and convex contour. We expect it to be crudely stratified and have larger particle sizes at its apex than at its toeslope, though exceptions are numerous. Furthermore, its lithology should directly reflect its *provenance*, i.e., the kinds of rock in its source area.

The common and geological languages do have some simple landform groupings. A mountain range comprises peaks, ridges, spurs, and canyons. A valley has its rim, walls, terraces, inner-valley scarp, and floodplain. Glacial drift comprises till plains, outwash plains, kettle moraine, and end and recessional moraines. Dichotomies are as common as groupings. For instance, uplands and lowlands are known to all. Originally, these terms referred to the habitats of those people close to the sea and others back in the hills of northern Europe. So uplands and lowlands had strong cultural overtones. In our present soils context, the terms imply well drained versus poorly drained for some people. Others see them as erosional versus depositional areas, or mountains versus plains, high elevations versus low, or above flood or tide versus periodically inundated. Upland and lowland has been so variously used as to be almost meaningless.

Other landform names involve geographic overlap and illustrate the numerous physiographic descriptors available in the language: a valley wall may as well be called a valley slope, a hillslope, or a mountain slope. Mountain footslopes merge somehow with, or could be called the piedmont[6]. Fluves (drainageways) cannot be conceived without interfluves (the watersheds between streams, or divides), yet, depending on scale, a watershed may be occupied by numerous, progressively smaller, tributary fluves, each with its own interfluve. But we can find all these physiographic descriptors useful.

First, we must use utilitarian terms where morphogenetic terms are not available. Second, we have to accept the fact that many, if not most, polypedons are not coextensive with many familiar landforms, that the same kind of soil can occur on different landforms, and that several soils can occur on the same landform. Selection of names at an appropriate hierarchical level will minimize the scale problem. Willingness to list several physiographic positions should solve the problem of a soil occurring in various positions. Reference to various landform elements or slope components can help explain a pattern of different soils on a single landform. Third, where adjacent soils on a landform, such as a floodplain, or smooth fan skirt, do not show any physiographic clues to their boundaries, we should say so. We should also tell where the soils occur within the landform and suggest other clues for location such as vegetation.

Soils are related to landforms, but the geomorphic events that have created various landscapes are not the only factors that have determined soil patterns. Landform analysis helps soil mapping, but soil maps show the integrated effects of many environmental factors in addition to geomorphic events. Also, soils can be mapped with precision and objectivity not even approached by landform mapping.

[6]The very general and useful term *piedmont* is used for areas, plains, slopes, glaciers, or foothills at the base of, and rising to mountains. It derives from the Italian Piemonte region at the base of the Alps (A.G.I., 1972).

BASIN AND RANGE LANDSCAPES

The landscapes of the Basin and Range Province (Fig. 1) are visually dominated by isolated mountain ranges rising abruptly from broad, alluvium-filled desert basins. However, these ranges occupy only about 20% of the landscape in the southern, and 35% in the northern part of the Province. Huge intermontane basins areally dominate the Province. Several erosional desert stream valleys and a few dissected plateaus are included.

The mountain ranges are characteristically many tens of miles long, are narrow and fairly linear, and rise steeply thousands of feet to continuous though sometimes jagged crests. The long ranges roughly parallel each other in north-south trends. They are close enough that their intermontane basins show north-south elongation. Though less spectacular, isolated small mountain masses are not uncommon. Since these also are surrounded by broad alluvial slopes, the general landscape character of isolated mountains with wide plains[7] sloping away from them is maintained.

The mountain ranges are mostly tilted fault blocks strongly modified by erosion. Commonly, both sides are equally steep and ravined or penetrated by deep canyons. Some ranges have broad, flattish to rolling crests and others have sharp and precipitous crests. Yet other ranges, particularly in Nevada, have broadly rounded crests which fall away along lateral ridges that have strikingly rounded crests and long smooth slopes themselves. Extrusive volcanic and sedimentary bedrock (including much limestone) are regionally dominant and locally intermixed, although some igneous-intrusive ranges and

[7]The generic term *plain* is used for any flat, or undulating, or even rolling area, large or small, which includes few prominent hills or valleys and may have considerable overall slope and local relief. Plains usually are at low elevation, relative to some adjacent highland area though the elevation above sea level may be great. In comparison, a *plateau* is an extensive, relatively-level to sloping area that stands at a notably higher elevation than adjacent areas and drops steeply to them on some side. It is commonly dissected by deep valleys, has considerable local relief, and may be surmounted by hills or mountains (A.G.I., 1972). Both terms suggest an extensive, smooth surface, or accordant surfaces, at the expense of ignoring possible prominent local dissection, relief, or slopes highly significant for soil patterns.

igneous masses intruded into volcanic or sedimentary ranges also occur (Fenneman, 1931).

The broad intermontane basins are deep, alluvium filled, structural depressions that reflect either the downdropped side of one tilted bedrock block that rests against the upthrown side of another tilted block along a fault line, or that reflect the downdrop of a more nearly horizontal bedrock block (a graben) along fault lines between two upthrown blocks (horsts). Surface drainage from many of these structural depressions has been blocked by a complete ring of bounding mountains. Or, more commonly, where the depression is bounded by two high mountain ranges surface drainage is closed off on the other two sides by lower bedrock hills or by dams of alluvium spilled out of particularly large mountain valleys (i.e., alluvial divides). Such centripetally, or internally drained desert basins have been called *bolsons* in the vernacular of the southwestern United States since at least the early 1800's (Tolman, 1909), the term having been derived from the Spanish word for "purse." As some bolsons filled with alluvium, it spilled over a low bedrock divide. This resulted in external drainage. Other once closed bolsons have been opened to external drainage by headward eroding streams that have cut through bedrock or alluvial divides. Such externally drained basins are aptly called *semi-bolsons* (Tolman, 1909) since the majority of their landforms are like those of bolsons. Some semi-bolsons are traversed by perennial desert streams fed from mountain sources. Others have only the topographic possibility for external drainage but seldom do under the present climate. *Bolson* and *semi-bolson* denote *drainage basins,* including the bounding mountains. They are characterized by a broad structural depression filled with alluvium. In practice, the terms also are loosely used to describe types of *intermontane basins.* The latter term, when used in a structural sense, refers only to the structural depression, regardless of its surface-drainage type. However, its contraction *basin* is also used in a loose generic sense for bolsons and semi-bolsons.

Bolsons and semi-bolsons are much much wider than stream valleys of equal relief that were cut by erosion. Construction of their gross topographic form through alluvial filling of broad structural depressions (at least to the level of spillover, or until drainage capture), rather than by erosional excavation, has created two highly distinctive *major physiographic parts:* the *piedmont slope* and the nearly level *basin floor.* The bounding mountains may be considered a third major physiographic part.

The piedmont slope must be considered a strictly gross topographic form that includes all of the noticeably sloping land from the bounding mountain front down to the nearly level basin floor. The steep mountain front joins the relatively gentle piedmont slope so abruptly that this slope break has been termed the *piedmont angle.* As a rule-of-thumb, hilly and mountainous terrain has dominant slopes steeper than 15%. Within the intermontane basins, however, slopes other than minor erosional scarps are less than 15%. Toward the centers of the basins, the piedmont slope flares out onto the basin floor. Bolsons have a playa, or ephemerally flooded lake, on their floors that is the final sink for runoff water and sediment[8]. Semi-bolsons have an axial stream across their floors.

Origins of Landforms Related to Soil Patterns

The bounding mountain ranges, piedmont slopes, and basin floor comprise a view of an intermontane basin as seen at a distance. The old, very general term, alluvial plains[9], has been likewise used to broadly encompass the entire piedmont slope and basin floor of such a distantly viewed basin, with the possible exception of the playa. Similarly, the old, southwestern U.S. term, bajada, broadly encompasses the piedmont slope. Both terms, and most of their synonyms[10] take such a far view that they ignore local relief and various age surface components occurring in characteristic patterns. Hydrologic and sedimentary positions that determine soil patterns are also ignored. On closer view, not only are the basin floors and piedmont slopes seen to be complex, but the mountain fronts may be deeply embayed by alluvium filled valleys, some of which open into intramontane basins. These mountain valleys contain landforms similar to those of the great piedmont slopes.

The piedmont slopes and basin floors are largely comprised by a few *major landforms*—mountain-valley fans, alluvial fans, fan piedmonts, alluvial flats, and alluvial plains[9]—that were largely constructed during early-Pleistocene time or earlier. Since about mid-Pleistocene time, these particular major landforms have been modified by recurrent erosion and deposition cycles[11] separated by periods of stability and soil formation. Only parts of these major landforms were cut away by periodic erosion or buried by periodic sedimentation during each of the cycles. Thereby, smaller *component landforms,* their *landform elements,* and their *slope components* have been created on these particular major landforms. This resulted in a mosaic of old, remnantal land surfaces and relatively young land surfaces *that more nearly accord with individual soils* than do these major landforms. Several other landforms that are also called major landforms for various reasons—ballenas, fan skirts, beach plains, lake plains, and playas—were themselves created by the cycles of erosion and deposition. They have been left largely intact by the latest cycles so that they also accord fairly well with soils.

The bolsons recurrently filled with lakes during the Pleistocene pluvials (cooler or moister periods associated with periods of glaciation elsewhere). Beaches and lake plains are prominent relicts from these lakes. The semi-

[8]Some bolson floors have been broken by faulting, or they have been tilted or warped (i.e., in response to bedrock faulting), creating new, lower base levels and resultant erosion and deposition cycles. But most seem to have been stable since Pleistocene time. This is the situation described here.

[9]The term *alluvial plain* is used in this bulletin in a very restricted sense for relict floodplains or fan-deltas of major Pleistocene streams that crossed or were built onto a basin floor (Hawley, 1980).

[10]Synonyms that have been used for *bajada* (also bahada) include: apron, alluvial apron, mountain apron, fan apron, debris apron, alluvial plain, compound alluvial fan, piedmont alluvial plain, piedmont plain, waste plain, piedmont slope, gravel piedmont, alluvial bench (A.G.I., 1972).

[11]Erosion in the bounding mountains or on the piedmont slopes is accompanied by deposition on the piedmont slopes or basin floor unless the sediment is carried out of a semi-bolson.

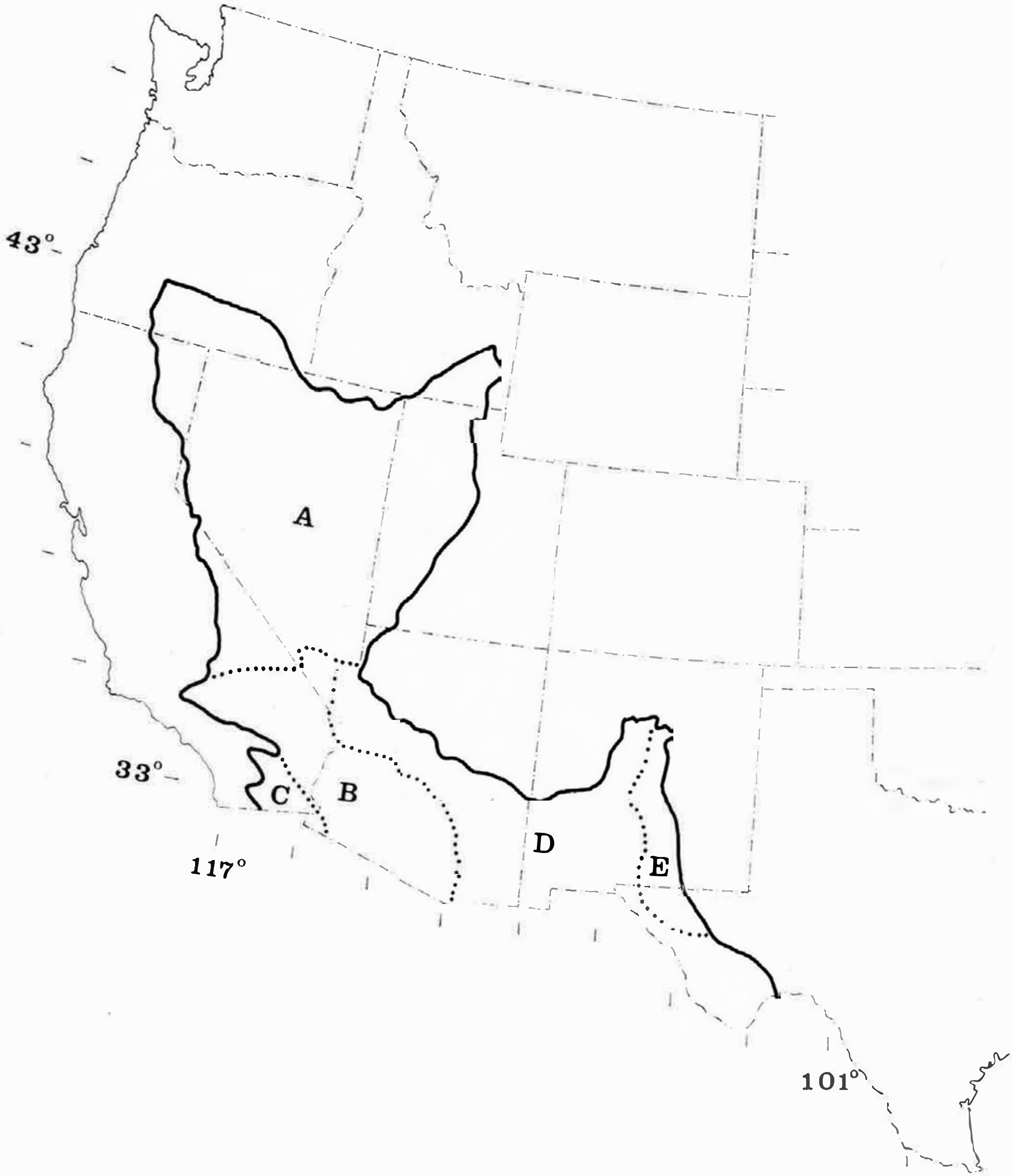


Figure 1. The Basin and Range Province and its Sections in the western United States: Great Basin section of isolated ranges separated by aggraded desert plains *(A)*; Sonoran Desert section of widely separated short ranges in desert plains *(B)*; Salton Trough section of desert alluvial slopes and delta plain *(C)*; Mexican Highland section of isolated ranges separated by aggraded desert plains *(D)*; Sacramento section of mature block mountains of gently tilted strata, block plateaus, and bolsons *(E)* (after Fenneman, 1928).

bolsons seem to have been subjected to recurrent cycles of erosion radiating out from their axial drainageways during the transition to the dry periods that followed each pluvial. Erosion on the piedmont slopes and within the bounding mountains also seem to have occurred in the bolsons during these transition periods. The relatively moist pluvial periods are thought to have been periods of landscape stability, of weathering to produce detritus in the mountains for later erosion and movement to the basins (Hunt and Mabey, 1966), and of soil formation. Some other cycles of erosion and deposition were initiated by faulting along the mountain fronts (Bull, 1964), and in some cases, across the piedmont slopes. However, those erosion-deposition cycles and periods of stability which have had most extensive regional effects on soil formation during late-Pleistocene and Holocene time seem to have been the result of climatic change rather than tectonic uplift (Hawley, 1980).

Similar patterns of minor landforms were created along the large desert stream valleys that are fed from mountain sources and were recurrently incised during the Pleistocene pluvials. The valleys of the Colorado, Rio Grande, Humboldt, Truckee, Carson, Walker, Bear, Jordan, and Seiver rivers are major examples within the Basin and Range Province. Tributaries to these rivers that headed in semi-bolsons and similar axial drainageways that emptied into adjacent bolsons cut smaller, but locally prominent valleys in concert with the larger streams. Eroding arroyo valleys carried the effects of periodic incision of the desert stream valleys far beyond the valley walls onto piedmont slopes in many locations. The minor valley-border landforms related to these events have also determined soil patterns (Ruhe, 1967; Hawley, 1980).

The Basin and Range Province is a desert area, but its very identifying landforms make it peculiar among the world's great deserts. Those other deserts are mostly characterized by vast plains, flats, and depressions. Many are extensively blanketed by eolian sand. The high mountains of the Basin and Range Province are relatively well vegetated. They discharge water into their desert basins annually and even flood the playas with some regularity whereas aridity is unrelieved for great distances in most other great deserts. The pans, flats, depressions, and deflation basins of those other deserts have only local, infrequently activated watersheds. Even relict Pleistocene lake features are apparently less common or prominent there than in the bolsons of the Basin and Range Province (Lustig, 1968).

CLASSIFYING AND NAMING LANDFORMS OF INTERMONTANE BASINS

Purposes and Categories

This morphogenetic classification of landforms uses the *shapes, genetic relations,* and *geographic scales* of the topographic forms seen in the field to construct its classes and categories. The landforms of intermontane basins are first grouped in two general classes. These are then successively divided into smaller and genetically more homogeneous classes in the several categories of this classification. In order, the categories are *(I) major physiographic parts,* each of which is made up of several genetically related *(II) major landforms.* They in turn may be comprised of several more genetically related *(III) component landforms.* The component landforms are about the smallest features that one would consider as a single unit in combined terms of their form, constituent materials, and genetic history. But some component landforms, such as fan remnants, have distinctive topographic parts with quite different geomorphic histories. A fourth category of *(IV) landform elements* recognizes these parts. A fifth category of *(V) slope components* allows those landform elements that are erosional surfaces to be subdivided into their genetic components (Tables 1 and 2).

For soil survey applications, it would be most convenient if somewhere in the hierarchy, the landform classes corresponded to individual soils. The very purposes of a landform classification, however, prevent such classes being gathered in a single category. *Age* is the primary genetic factor that determines coincidence of individual soils and landforms. A few of the *major landforms* and all of the *component landforms* (described later) are comprised of land surfaces of one age or only a few ages. Where more than one age of surface occurs on these landforms, the surfaces of different ages are either *landform elements* or *slope components.* Thus, physiographic positions that are specific for most individual soils can be described. They are not apt to be at the same categorical level, however.

Some of the even most-specifically designated landforms will not coincide with certain soil boundaries because genetic factors of soil formation, in addition to those that are attributes of landforms, determine where some soils occur.

Fan and Remnant Terminology

The terms *fan* and *remnant* are used in both specific and generic senses in this landform nomenclature. The word *fan,* in the names *mountain-valley fan, alluvial fan, fan piedmont, inset fan, fan apron,* and *fan skirt,* indicates that these landforms have a generic affinity in that each is (1) a constructional landform, is (2) composed of crudely sorted and stratified alluvium with or without debris flow deposits, and (3) occupies a position downslope from some higher landform from which its alluvium was derived. These three strong genetic implications come from the classic concept of the *alluvial fan*. The fourth and fifth criteria for the alluvial fan itself is that (4) it have a fan-like shape in plan view, or a semiconical form, with (5) its apex at a point source of alluvium. Obviously, these last criteria do not apply to the related landforms, but they do share a sixth feature: (6) all occur on the piedmont slope.

A *remnant* is defined here as a remaining part of some landform or geomorphic surface which has been otherwise either destroyed by erosion or buried under sediment. Logically, an erosional remnant must be older than the destructive erosion cycle. Also, it must be older than any land surface or landform created by that erosion (cf., Fig. 8 and 9). A nonburied remnant must also be older than the sediment that buried part of the original landform or surface and older than the constructional surface built by that depositional event (cf., Fig. 10). Recognition of remnantal land surfaces is the basic tool for establishing relative ages of land surfaces (i.e., geomorphic surfaces) and potential boundaries between different age, and perhaps different kinds of soils.

The word *remnant* can be combined with various landform names to explicitly identify a relatively old element of a land surface, and to imply the genesis, composition, and landscape position of the original landform, e.g., alluvial-fan remnant, fan-piedmont remnant, fan-apron remnant, or basin-floor remnant. Some of these very specific identifications are potentially confusing because the definition of the original landform may involve its position relative to remnants of some older landform upslope or downslope. A fan apron, for example, is formed by deposition of an alluvial mantle over an older surface of a fan piedmont (cf., Fig. 10). By definition, erosional remnants of that older surface must occur upslope since the older upslope surface was either part of the source of the fan-apron alluvium, or the alluvium has been carried past its remnants in inset channels. A nonburied, remnantal segment of the older surface must also occur downslope since that distinguishes a fan apron from a fan skirt. If this fan apron is then prominently dissected, its remnants may be difficult to distinguish from the downslope, yet older fan-piedmont remnants by topographic clues. Furthermore, with respect to the younger surfaces created by its dissection, the surviving portions of the fan apron are merely remnants of some older surface. If clues, such as topographic breaks, soils on the land surface, or buried soils can be used to identify and at least imaginatively map the three ages landforms—or more correctly, geomorphic surfaces—the very specific "fan-apron remnant" name could then be used in this example.

In most soil mapping, however, there is neither need nor time for such detailed landscape analysis. It may be best to simply call all these possible types of remnants merely *fan remnants*. Where several such fan remnants occur in stepped sequence, they can be identified as relatively young or old fan remnants. Their ages relative to each other and to recent landforms and their generic identification as *fan* forms are more significant than their exact original landform character.

For soil surveys, identification of landforms as fan or basin-floor remnants should be strictly limited to remnants that include some identifiable area of relict land surface. A relatively old fan-piedmont surface area that is surrounded by, and laterally buried under adjacent fan aprons (i.e., a *nonburied* remnant), comprises only a relict surface. But an *erosional remnant* of a dissected fan which stands above the surrounding, younger surfaces as a flattish topped ridge, or bench, comprises both a *relict-surface summit* and younger, erosional, *remnant sideslopes*. The whole elevated landform is seen and thought of it as a part of a preexisting landform that was built of a real depth of some material in addition to being a mere surface form. Therefore, it is reasonable that the concept of an erosional-remnant *landform* includes the younger sideslopes cut into the soil and material that formed the original surface. The only caution, or demand, for soil survey purposes is that landforms which are identified as fan or basin-floor remnants must include some relict-surface area.

However, there are distinctive erosional remnants (in the broader meaning of this word) of alluvial materials which once formed fans but which no longer include relict summit areas. A special morphogenetic term is needed for such remnants. This special situation is found where older piedmont landforms have been closely dissected, and the shoulders of the eroding sideslopes have joined and destroyed the relict surface that once formed a flattish remnant summit. Commonly there will be several of these round topped ridges paralleling each other or forming a digitate pattern that mirrors dendritic erosion (cf., Fig. 5 and 6). These narrow, rounded ridges will have accordant crests that can be used as evidence that a land surface once existed at about their present elevation, and had about the configuration of a plane drawn across their accordant crests. These accordant ridges are called *ridgeline remnants*. Their convex crests and straight to concave sideslopes are not remnants of that hypothesized older land surface. The *line* in *ridgeline* emphasizes that these peculiar ridges include no relict summit area, and that the ridgelines, by their accordance, are the only clues to something gone. If one views such ridges in the context of their actual crest and sideslope surfaces, i.e., as landforms in their own right, then they are called *ballenas*, which are discussed later.

A CLASSIFICATION OF THE LANDFORMS IN INTERMONTANE BASINS

The internally-drained *bolsons* are the most distinctive physiographic feature of the Basin and Range Province. Since their landforms (Table 1) are quite similar to those of semi-bolsons, *bolsons are used as a paradigm, or model, for the landforms of intermontane basins.* Landforms of semi-bolsons (Table 2) differ primarily on the basin floor, and only the differing landforms there are discussed in detail in a later section.

Piedmont Slope

The first division of intermontane basins into *piedmont slope* and *basin floor,* shown in Figure 2, separates two very large areas of sloping versus nearly level land, of differing alluvial provenance, and of partly erosional versus dominantly depositional landforms (Table 1). The bounding mountains are a potential third major physiographic part, but are not treated in this classification. The general piedmont slope ranges from about 8 to 15%, near the mountain front, to about 1% where it merges with the basin floor, but includes short erosional slopes as steep as 30% where it is dissected. A bolson floor slopes toward its playa at less than about 1% gradient.

Along the piedmont slope, the provenance, or source area, for the fan alluvium of any short reach is a few mountain valleys directly upslope since the alluvium is moved downslope at about right angles to the mountain front. Fan lithology commonly may be predicted from the bedrock lithology of the source valleys (Ruhe, 1964). As the alluvium is moved onto the basin floor and toward the playa of a bolson, or out of a semi-bolson, much of the sediment travels parallel to the mountain fronts. Sediments from many mountain valleys are consequently mixed. If the rock detritus in the mountains includes resistant gravel and stones, the alluvium of the upper piedmont slope is stony and coarse textured, the toeslope alluvium is medium textured and fine gravelly, or nongravelly, and the alluvium on the basin floor is fine textured. Great variations in gravel content can occur on specific piedmont slopes, however, and gravelly strata within basin-floor alluvium are not rare.

The piedmont slope is a very gross topographic and sedimentary division of an intermontane basin. In turn, it has several large topographic parts, or *major landforms. Mountain-valley fans* occur where the alluvial fill of the piedmont extends on into mountain valleys. Where the margin of the piedmont slope against the mountain front consists of an erosion surface cut into bedrock, it is a *rock pediment*[12]. Where the upper part of the piedmont slope is built of alluvium spilled out of narrow mountain valleys spaced along the mountain front, the slope is comprised of *alluvial fans.* Across the middle piedmont slope, the toeslopes of adjacent alluvial fans coalesce laterally to form the *fan piedmont.* In almost all basins, the middle and upper piedmont slopes have been dissected and the eroded sediment spilled out onto the lower piedmont slope to form a *fan skirt.*

Like the piedmont slope, its major parts—the mountain-valley fans, rock pediments, alluvial fans, fan piedmont, and fan skirt—are all but the last large topographic and constructional forms that were largely built by about mid-Pleistocene time. Since then, all of these major landforms, except the relatively young fan skirts, have been subjected to recurrent erosion and deposition cycles that have either *partially dissected* most examples of them into *component landforms* (such as fan remnants and inset fans), or have *built component landforms* (such as fan aprons) on their relatively old surfaces. These younger, subsidiary landforms are *components* in the sense that when they are viewed together with surviving relict areas, they compose the large geographic area of the original major landform (cf., Fig. 7). In some intermontane basins, large relict examples of these major landforms have not been dissected and present an extensive relict surface unbroken by younger component landforms. In a few basins, small alluvial fans and very narrow fan piedmonts that were built by late-Pleistocene or Holocene deposition have not been dissected and also lack component landforms. Where dissection of the piedmont slope was initiated early, or was deep and closely spaced, one more major landform, the *ballena,* has been created from old fan alluvium.

In most basins, the mountain-valley fans and alluvial fans of the upper piedmont slope are prominently dissected. Ballenas and the oldest fan remnants are apt to occur there with inset fans between some of them. Downslope, across the fan piedmont, dissection ordinarily is shallower and the fan remnants broader. Dissection may be slight and relict fan-piedmont surface extensive. Alluvium from fanhead trenches, interfan drainageways, and onfan drainageways (cf., Fig. 7) has spilled out as discontinuous fan aprons on many fan piedmonts. Alluviation within these drainageways has formed more inset fans. In many basins, some of these drainageways that cross the fan piedmont, and others that rise on it, have built a fan skirt where they dumped their sediment along the lower piedmont slope.

Thus, the piedmont slope can be thought of as comprised of several crude *geographic zones* of major and component landforms that roughly parallel the mountain front. These are illustrated in Figure 3. The upper zone includes mountain-valley fans, rock pediments, ballenas, and alluvial fans and the component landforms created from the fans. The fan piedmont and its component landforms characterize the middle zone. The lowermost zone is comprised of the fan skirt or may be absent if the fan piedmont is little dissected and no fan skirt has been built.

[12]Other pediment surfaces cut across unconsolidated sediments also may occur on the piedmont slope (p. 24). Rock pediments are discussed on page 14, and pediments in the generic sense on page 36.

Figure 2. The major physiographic parts of an internally-drained intermontane basin, or *bolson*: the *piedmont slope (P)*, and the *basin floor*, or more specifically, the *bolson floor (F)*. This schematic diagram shows part of an elongated bolson with bounding mountain ranges on the near and far sides and the far end of the bolson cut off by hills. The dotted-line drainageways suggest positions of major landforms (cf., Fig. 3). Neither the playa nor the drainageways of the floor are shown.

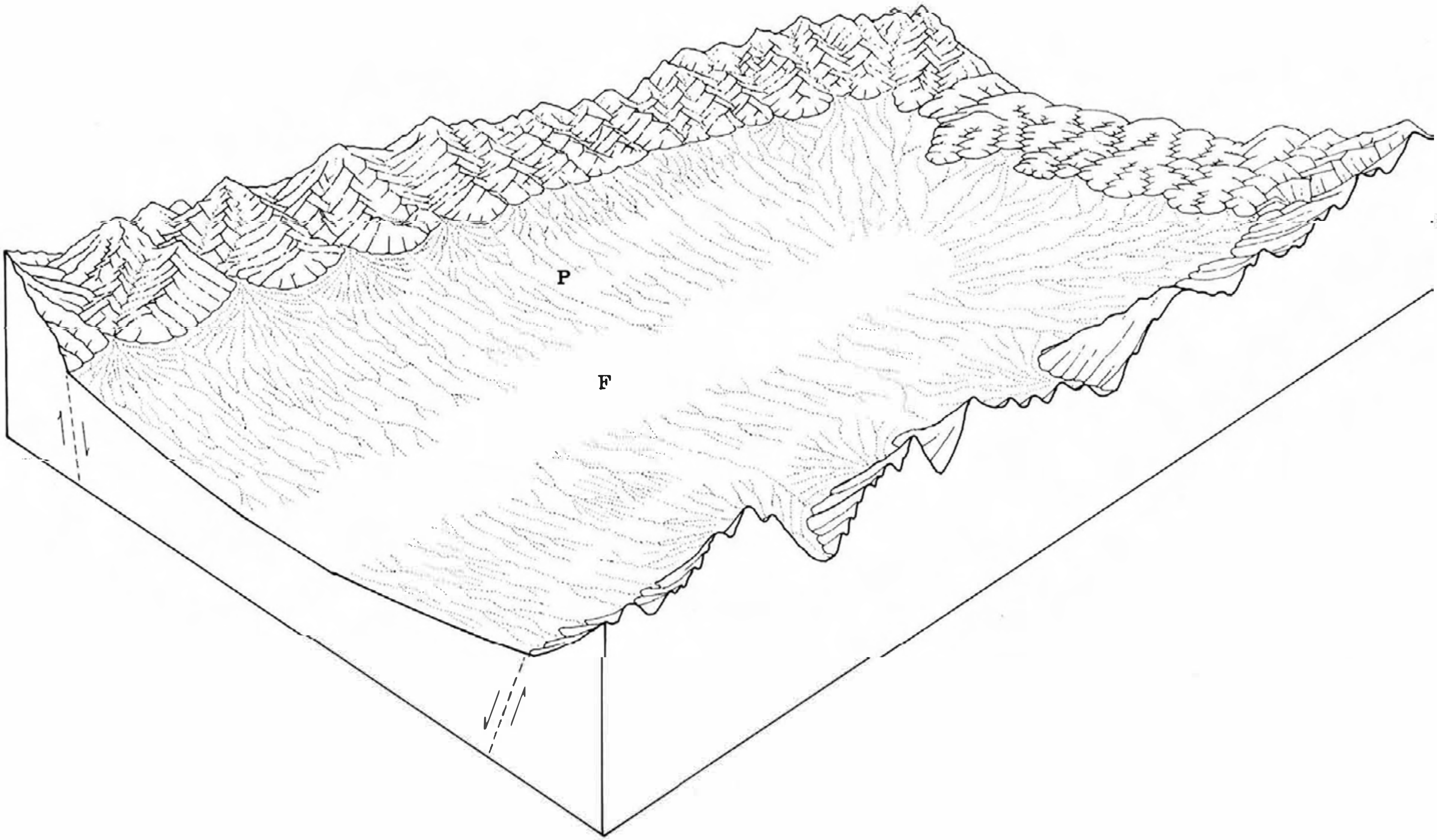


TABLE 1
CLASSIFICATION OF BOLSON LANDFORMS

landforms			parts of landforms	
I Major Physiographic Part	II Major Landform	III Component Landform	IV Landform Element	V Slope Component
Bounding Mountains	(not defined)	...	...	...
Piedmont Slope	Mountain-Valley Fan	Erosional Fan Remnant	Summit[1]	
			Sideslope	Shoulder
				Backslope
				Footslope[2]
			Partial Ballena[3]	Crest
				Shoulder
				Backslope
				Footslope
			Channel[4]	
		Inset Fan	Channel	
	Rock Pediment[5]	Rock-Pediment Remnant	Summit, or	Crest[6]
			Sideslope	Shoulder
				Backslope
				Footslope
			Channel	
	Ballena	...	...	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
	Alluvial Fan	Fan Collar[5]	Channel	
		Erosional Fan Remnant	Summit	
			Sideslope	Shoulder
				Backslope
				Footslope
			Partial Ballena	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
	Fan Piedmont	Erosional Fan Remnant	Summit	
			Sideslope	Shoulder
				Backslope
				Footslope
			Partial Ballena	Crest
				Shoulder
				Backslope
			Channel	
		Inset Fan	Channel	
		Fan Apron	Channel	
		Nonburied Fan Remnant	Channel	
		Beach Terrace		

Piedmont Slope continued on next page

TABLE 1—Continued

........landforms........			........parts of landforms........	
I	II	III	IV	V
Major Physiographic Part	Major Landform	Component Landform	Landform Element	Slope Component
	Pediment[5]	Pediment Remnant[5]	Summit	
			Sideslope...........	Shoulder
				Backslope
				Footslope
			Channel	
	Fan Skirt	. . .	Channel	
		Beach Terrace		
Basin Floor (Bolson Floor)	Alluvial Flat	Relict Alluvial Flat	Channel	
		Recent Alluvial Flat	Channel	
	Alluvial Plain			
	Sand Sheet	Sand Dune (Parna Dune[7])	Interdune Flat	
	Beach Plain	Offshore Bar		
		Barrier Bar		
		Lagoon	Channel	
	Lake Plain	Lake-Plain Terrace	Channel	
	Playa	Floodplain Playa	Channel	

[1]The summit landform element is synonymous with the summit slope component.
[2]A footslope alternatively may be called a pediment. The toeslope component is not listed because ordinarily it would be part of an inset fan, fan apron, fan skirt, or alluvial flat.
[3]The term *partial ballena* is an alternative name for the portion of a remnant sideslope which forms a spur.
[4]The channels associated with various landforms may be within or between them or absent.
[5]Not a common landform.
[6]A rock-pediment remnant may have either a summit or a crest.
[7]Parna dunes are not known to form parna sheets in the Basin and Range Province, but they do in Australia.

Figure 3. The geographic zones, or positions, in which the major landforms of bolsons commonly occur. The upper piedmont zone comprises *mountain-valley fans* within the bounding mountains *(M)*, *alluvial fans (A)*, and *ballenas (B)* (shown as a group of parallel ballenas would occur, others may occur individually, cf., Fig. 5 and 6). The middle piedmont zone comprises the *fan piedmont (P)*, and the lower zone the *fan skirt (S)*. The bolson floor comprises an *alluvial flat (F)*, *playa (Y)*, and possibly other major landforms such as beach plains.

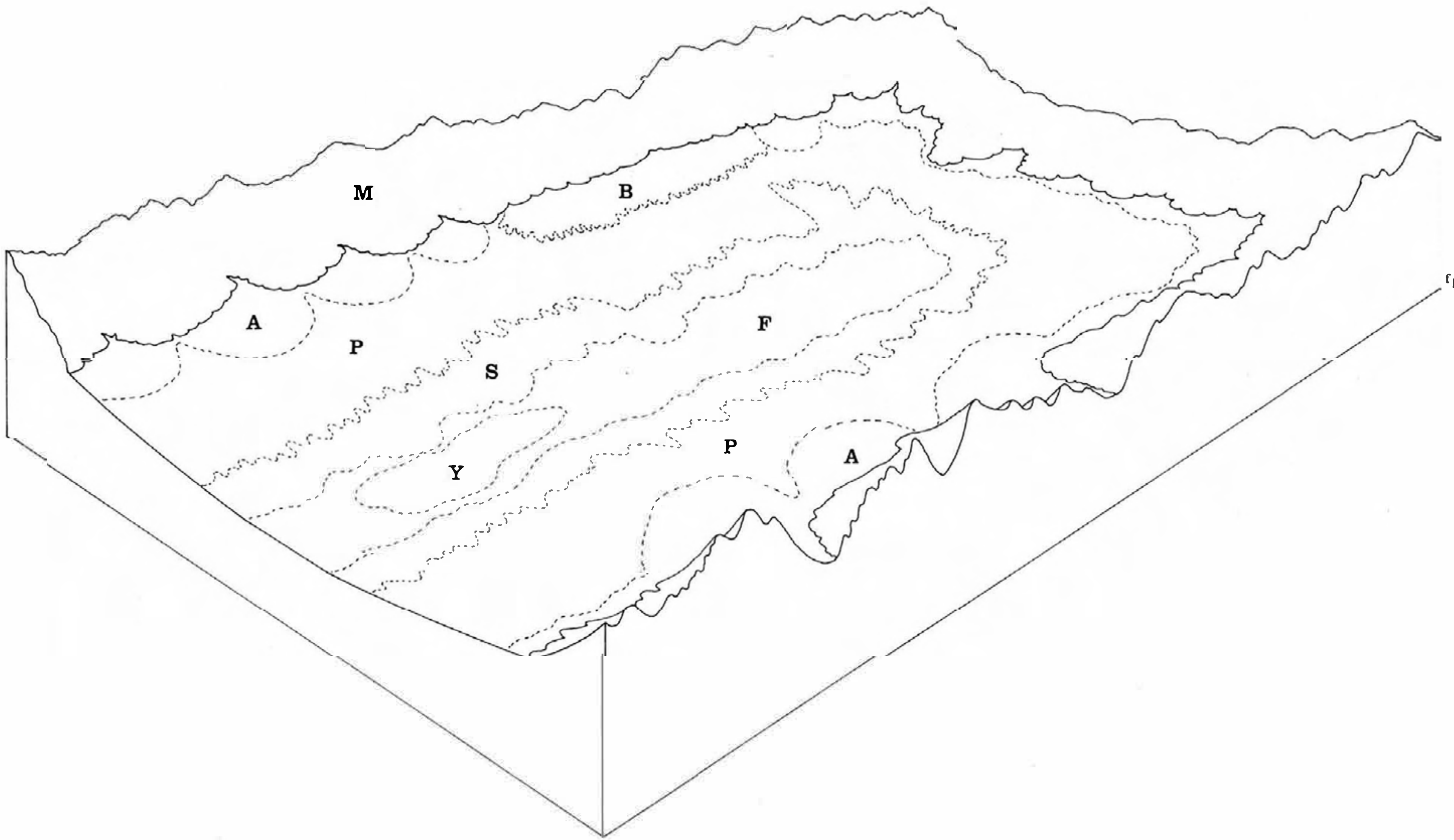
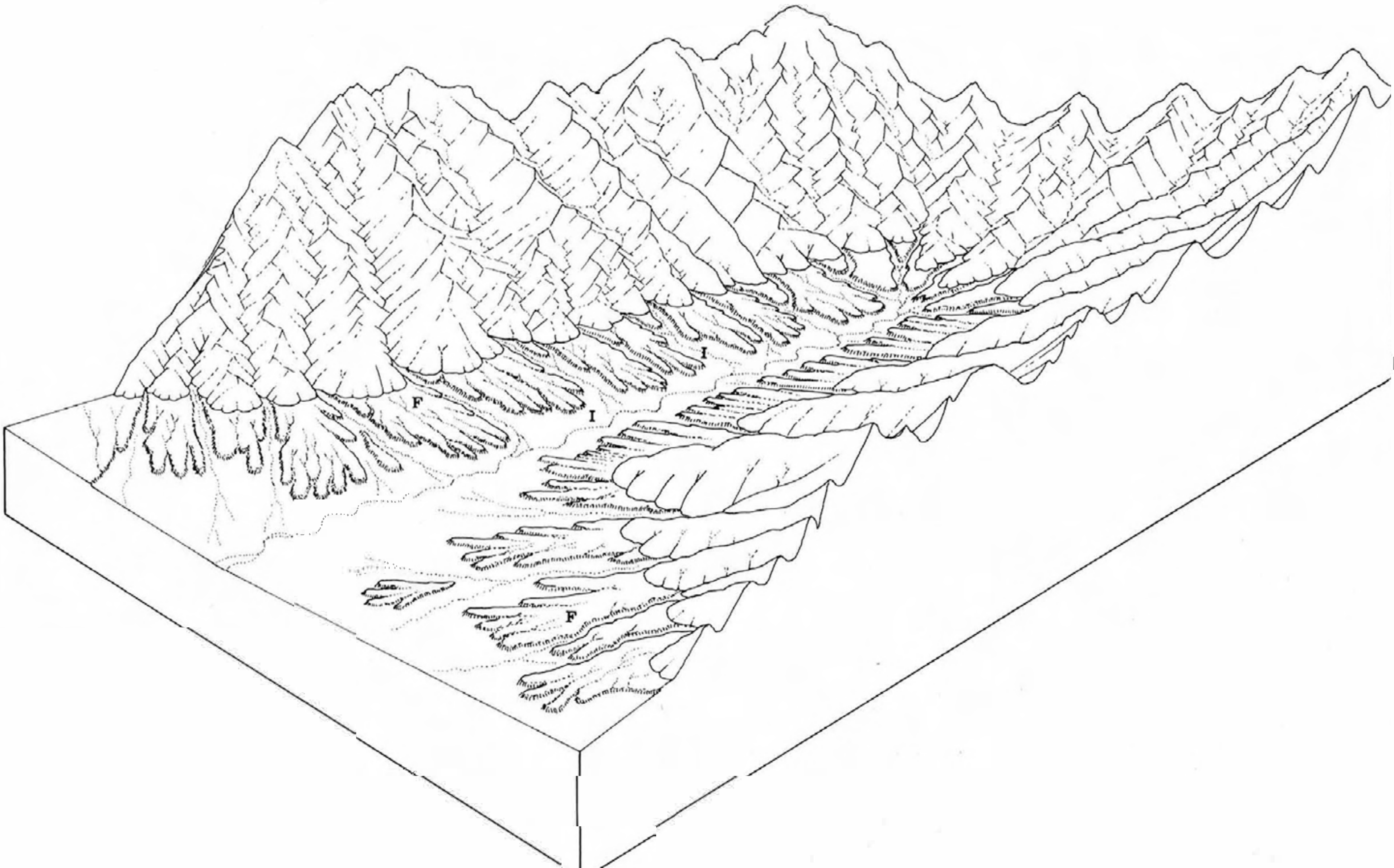


Figure 4. A dissected *mountain-valley fan* in a mountain valley embayment of the piedmont slope. The dissected fan is comprised of *fan remnants (F)* and *inset fans (I)* between the fan remnants and down the axial drainageway.



Mountain-Valley Fan

Mountain-valley fans occur where the alluvial fill of the piedmont slope extends into wide mountain valleys and also within intramontane basins. In comparison, steep-sided mountain canyons and ravines commonly have been swept clear of rock debris. Their slopes plunge directly to the stream channel or have only a narrow colluvial slope separating them from the channel. The wider mountain valleys and intramontane basins mostly have been filled at some past time with alluvium some tens of feet thick. Alluvium spilled out of gullies of the valley sideslopes may form small, distinctively conical alluvial fans, or *fanlettes*[13], but commonly these miniature fans have coalesced to form an alluvial slope only transversely undulating that is called a *mountain-valley fan* (Table 1). The coalescent fans from either side of the valley meet along the axial stream channel if it has not been incised.

However, most mountain-valley fans have been dissected by erosion cycles that have also affected the lower piedmont slope. As shown in Figure 4, *fan remnants*[14] or *ridgeline remnants* (i.e., ballenas[15]) separated by channels of ephemeral streams or by *inset fans*[16] remain. There may be stepped sequences of remnants of the original fan surface and inset-fan remnants or erosion may have reduced all remnants in the valley to ballenas.

Rock Pediment

Rock pediments, or erosion surfaces of low relief that have been cut across bedrock, occur along the flanks of some mountain fronts as major landforms of the uppermost segment of the piedmont slope. Some rock pediments grade to, and their alluvial veneer merges downslope with the alluvial piedmont slope. The alluvial veneer over the cut-rock surface is called *pedisediment* and seems to be an integral feature of pediments, but their entire genesis is controversial (cf., Cooke and Warren, 1973, pp. 188-215; Ruhe, 1975, pp. 125-148). Other rock pediments in some semi-bolsons grade far toward the axial stream. These may be cut in weakly consolidated, very old basin-fill alluvium[17] (Royse and Barsch, 1971). Very short *rock-pediment notches* are found in some mountain valleys and along some mountain fronts as a narrow border between the mountain slope and alluvial fill downslope. Rock pediments ordinarily cannot be identified unless the cut-rock surface has been stripped of pedisediment or it is so thin that the rock surface crops out occasionally or is exposed in gullies. If the pedisediment is thicker than about five feet, there is serious question of the significance of rock pediments for soil surveys or if soils associated with them can be mapped.

Rock-Pediment Remnants

Most rock pediments have been dissected into remnants separated by wash channels. Their crests or summits and sideslopes do not have the consistent genetic implications for soil mapping that elements of fan remnants have. Rock-pediment remnants with narrow rounded crests are ridgeline remnants (but not ballenas) with possibly widely-varying ages of surfaces and soils. Remnants with flattish summits may be capped with pedisediment, but the pedisediment surface need bear little age relation to the cut-rock surface below it. Rather, it is apt to be related to a relict surface of downslope fans. That is where correlations between soils and landform ages should be made.

Recognition of rock pediments helps understanding landscape evolution, but they are not extensive enough to be more than locally important for soil mapping in most places other than the Sonoran and Mojave deserts of Arizona and California. Even there, alluvial fans are more apt than rock pediments to abut the mountain fronts and form the uppermost piedmont slope.

Ballena

Ballenas[18] are ridgeline remnants of fan alluvium that are distinctively round topped. Their erosional shoulders have met from either side to form the broadly and continuously rounded type of crest illustrated in Figure 5. The shoulders join backslopes that are broadly concave and have little or no straight portion (cf., Fig. 15-C). In ideal examples, the concave footslopes of adjacent ballenas join along an ephemeral wash channel in a notably concave fluve. Ballenas occur along some mountain fronts as groups of numerous semiparallel ridges that reflect incision of parallel drainageways (Fig. 6). They also occur on alluvial fans as isolated small groups of digitate spurs spreading from a trunk ridge (Fig. 5, left side). These reflect incision of dendritic drainageways into an ancient fan surface that has been obliterated. The narrow drainageways between individual ballenas converge downslope where they may be occupied by relatively wide, transversely flattish alluvial fills called *inset fans*[19]. Broad, deeply incised drainageways, or fanhead

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[13] The diminutive *fanlette* is introduced to have a term for small alluvial fans, less than a few tenths of a square mile in area, that have been built recently or have been preserved from dissection. Fanlettes display classic semiconical form and occur below major drainageways, such as valley-wall gullies, arroyos, or onfan drainageways where sediment is deposited within a valley or at the base of some large landform like a mountain-front alluvial fan. The large alluvial fans of the upper piedmont slope almost always have been dissected into component landforms, whereas fanlettes are nearly entire, though some are late-Pleistocene relicts.

[14] Fan remnants are erosional component landforms of mountain-valley fans, as well as of alluvial fans and fan piedmonts. They are discussed on pages 6-7 and 18.

[15] Ballenas are major landforms even though erosionally derived from mountain-valley fans. See pages 14-16 for a detailed discussion of them.

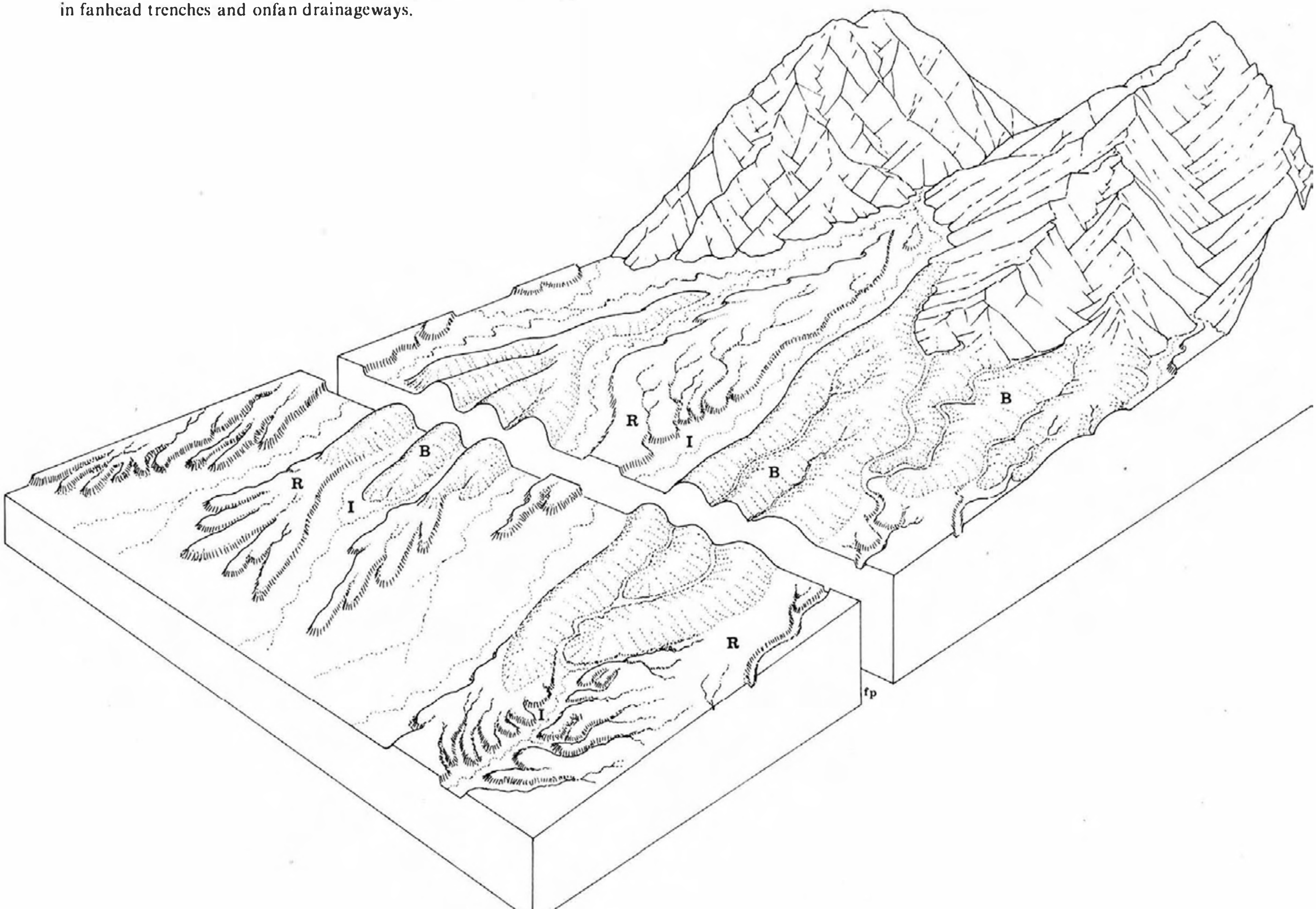
[16] Inset fans are component landforms of mountain-valley fans as well as of alluvial fans and fan piedmonts. For a detailed discussion of them see page 20.

[17] The concept of a pediment originally was defined for an erosional surface cut into bedrock. Ruhe's (1975) generic use of the term *pediment* for the footslope component of *all* erosional slopes—whether they are cut into bedrock or into unconsolidated sediments—is followed here. See page 36 for further discussion.

[18] The word *ballena* (pronounced *by-een-a*) is Spanish for whale. It also is the name of a village in eastern San Diego County, California, that is near several large, whaleback-shaped ridges that are cut from deeply weathered Eocene alluvium. This obvious metaphore used by those early villagers seemed appropriate for similar landforms of the Basin and Range Province (Summerfield and Peterson, 1971, p. 6, 22). The name "whaleback" also has been used colloquially for these landforms, but since it has been used previously for large desert sand ridges, bedrock residual hills of the tropics, and *roche moutonnées* (A.G.I., 1972, p. 792) it is not an appropriate neologism.

[19] Inset fans between ballenas compose part of the combined area of the two landforms, and in this sense are component landforms, but they are not the result of ballena dissection and subsequent partial aggradation, as they are of major fan landforms. Inset fans are described on page 20.

Figure 5. Two isolated groups of *ballenas* on a small part of a dissected, mountain-front alluvial fan near its apex. The landforms include *ballenas (B)*, erosional *fan remnants (R)*, and *inset fans (I)* in fanhead trenches and onfan drainageways.



trenches, issuing from mountain valleys and passing through areas of ballenas also may contain inset fans.

Ballenas range from narrow ridges about 15 feet high to broad ridges rising 100 or more feet above their flanking drainageways. The high relief ballenas commonly have straight backslopes that drop directly to the drainage channels, or to inset fans. The straight slope seems to reflect rejuvenated erosion in the fluve since this variety of ballena backslope is found above dissected fan piedmonts with stepped erosion remnants suggesting recurrent erosion cycles. Low-relief ballenas commonly lack a prominent, concave backslope. Their shoulders reach almost to the fluve bottoms instead.

Most ballenas occur on the upper piedmont slope where dissection is oldest. Within some intramontane basins and mountain valleys, former mountain-valley fans have been completely reduced to ballenas. Numerous semiparallel ballenas occur along considerable reaches of some mountain fronts. They may be high enough to suggest the appellation of "foothills". They also are apt to terminate downslope in a line that reflects an alluvial fault (Fig. 6). Just as commonly, digitate ballenas occur as small groups on or between large alluvial fans[20] (Fig. 5). Ballenas may also occur on the lower piedmont slopes of semi-bolsons or along a desert stream valley where arroyos radiating out from the axial stream have strongly dissected the piedmont. These ballenas are apt to be much younger than those of the upper piedmont slope.

When compared to the huge alluvial fans at the mountain front and to fan piedmonts, ballenas are relatively small major landforms. Where they occur on these other major landforms, they might be thought of as a component landform. But, a ballena is a unitary landform whereas the former two major landforms are almost always comprised of smaller component landforms. Ballenas represent a distinctive late stage of piedmont dissection. They have such distinctive soil patterns and geomorphic history that they are classified in the major landform category.

Soil Occurrence on Ballenas

Ballenas have a special meaning for soil occurrence. They commonly have the same kind of, or very similar soils on their crest, over their shoulders, down across their concave backslopes and footslopes, and sometimes even through a concave fluve and up onto an adjacent ballena[21]. This apparently reflects a situation where *all* of the ballena surface has been periodically modified by erosion, then *all* of it stabilized during intervening soil forming periods (cf., Gile and Grossman, 1979, pp. 618-621, 752; Ruhe, 1969, p. 129). Ballenas are fan remnants, but only in the sense that their alluvial core is a fan deposit and that their accordant crests roughly indicate where the vanished fan surface was, i.e., they are ridgeline remnants. The joining of the shoulders has obliterated or truncated the soil that once occurred on the relict surface of a remnant summit.

The ballenas occurring in large groups on the upper piedmont slope, or in small groups on alluvial fans and interspersed with alluvial-fan remnants, apparently achieved their form and had their surfaces stabilized during the Pleistocene since their soils are known to be Pleistocene relicts (Gile and Grossman, 1979; Mock, 1972). These soils either have clayey argillic horizons, indurated duripans, or petrocalcic horizons. They commonly cover the entire ballena unless its lower sideslopes have been recently rejuvenated by erosion. This correspondence of soil and landform has been seen frequently enough in Nevada to suggest it as a working hypothesis for soil mapping throughout the Basin and Range Province.

Ballenas, or more commonly, *partial ballenas*[22], found along the lower margin of dissected fan piedmonts, or among valley-border landforms where they have been modified by Holocene erosion, are apt to have Entisols (soils without diagnostic pedogenic horizons) across their surface, or Entisols on their sideslopes and a truncated remnant of a Pleistocene soil along their crest (cf., Gile, Grossman, and Hawley, 1969; Gile, 1975; Gile and Grossman, 1979, pp. 303-316). Their sideslopes have not been stable long enough for pedogenic soils to form to a degree that masks occurrence of any truncated relict soil that might persist along the crest.

The soils in the flanking washes or on inset fans between ballenas are apt to be different from those on the ballena since these deposits are ordinarily significantly younger than the ballena surface. The raw alluvium in the washes that head between ballenas demonstrates that there is some erosion from the ballena surface. This suggests that some slight soil truncation by sheet erosion may be a periodic or continuous process. The effective uniformity of soil cover on old ballenas suggests that any such process would minimally affect the entire rounded ballena surface.

Shoulder-Rounding as a Clue to Soils

Where relict Pleistocene soils with clayey argillic horizons, indurated duripans, or petrocalcic horizons occur on erosional fan remnants as the flattish summit, the shoulders of the remnant are apt to have a broad rounding similar to a ballena slope. Angular shoulders are most common on fan remnants of young, recently dissected fans or where lateral stream migration has undercut and rejuvenated the sideslopes. They are also common where a thick petrocalcic horizon has acted as a cliff-former and preserved the angular shoulder[23] above a straight backslope. These relations are seen frequently enough, at least in Nevada, that a hypothesis can be proposed for soil mapping: Where fan remnants of the middle and upper piedmont slope have broadly rounded shoulders, the soil on their summits should be old and have strongly differentiated horizons.

Alluvial Fan

Semiconical alluvial fans debouching from canyons and valleys form the uppermost piedmont slope along

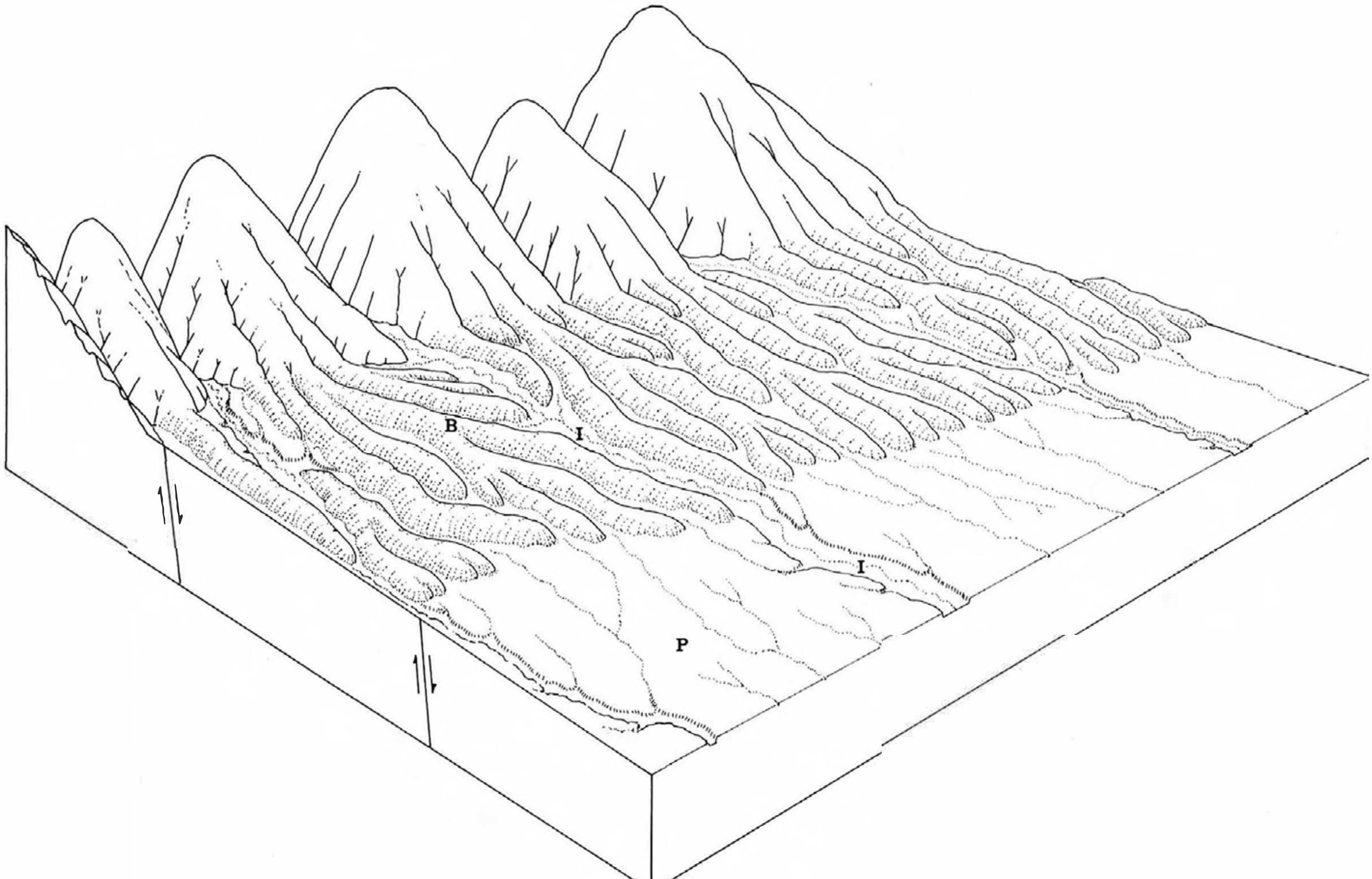
[20] Some old broad alluvial fans at mountain fronts have been almost completely reduced to low and wide ballenas by incision of dendritic onfan drainageways. When these fans are seen from the basin floor in low-sunangle light, the ballenas resemble a pattern of tightly fitted, gently rounded pillows.

[21] Lloyd Rooke and Harry B. Summerfield, Soil Scientists, first forcefully brought my attention to the soils of old ballenas in Nevada.

[22] Partial ballenas are fully rounded spurs attached to erosional fan remnants, and are landform elements of them. They are discussed on page 20 and illustrated in Figure 9.

[23] Even indurated duripans seldom preserve angular fan remnant shoulders.

Figure 6. A zone of semiparallel *ballenas (B)* along a mountain front. The linear terminus of the ballenas is a commonly observed reflection of alluvial faulting paralleling mountain fronts. A somewhat dissected *fan piedmont (P)* below the ballenas is composed of broad fan remnants and *inset fans (I)*.



most mountain fronts, as shown in Figure 7, rather than ballenas or pediments. Fans below small mountain drainage basins may be less than a square mile in area, but those that visually characterize the upper piedmont range from several square miles in area up to huge fans exceeding 40 square miles area and hundreds of feet thickness[24]. Except for the smaller, younger fans, the alluvial fans along the mountain front have almost all been deeply cut by prominent fanhead trenches issuing from the mountain valleys and closely dissected by onfan drainageways (Fig. 7). These major landforms should be thought of as only gross topographic and alluvial forms in the context of describing soil occurrence since their soil patterns are related to their component landforms created by erosion and deposition.

An alluvial fan, *sensu stricto*, is a semiconical deposit of variously sorted and stratified alluvium, with or without included debris flow deposits, which is planimetrically fan shaped and has its apex where a constricted valley debouches from a highland into a relatively broad lowland. Since an alluvial fan has a single source for its alluvium, its lithology directly reflects its provenance in the bedrock of its source drainage basin. Many fans are coarsest textured on their upper, or proximal slopes, and finest textured on their toeslopes, or distal parts, *but the bedrock provenance is the major control of texture.* Granitic provenances are apt to form fine-gravelly or coarse-sandy fans. Volcanic provenances are apt to form angular-stoney and very-gravelly fans. Provenances of sedimentary rocks rich in limestone result in fans that are stoney and gravelly toward their apices, grading to loamy textures far down the piedmont slope. The alluvial strata that form alluvial fans and fan piedmonts ordinarly are most gravelly at their base. They grade to loamy and less gravelly at their top, presumably reflecting sedimentation processes. However, eolian dust infiltration and pedogenic weathering may as commonly account for the loamy upper parts of surficial strata.

The great alluvial fans along the mountain fronts merge laterally to form a coalescent-alluvial-fan piedmont, or fan piedmont. Whereas the contours of the alluvial fans are prominently convex away from the fan apices, and concentric downslope, the contours straighten on the fan piedmont and nearly parallel the mountain front. Where particularly large alluvial fans abut laterally on each other, they form roughly triangular *interfan valleys* (Hawley, 1980). Drainageways from the fans, and from small mountain canyons between the large fan apices join to form a trunk *interfan-valley drainageway* down the valley and out onto the fan piedmont. It is one of the three major drainage systems of the piedmont slope (Fig. 7). Small, subsidiary alluvial fans, or *fanlettes*[13], may occur below the interfan-valley tributaries and within the interfan valley. The trunk drainageway is ordinarily occupied by an inset fan or it may be trenched.

[24] The wide range of sizes of alluvial fans is a good illustration of the completely *expansible scale* of most traditional landform concepts. When a landform name is used for a large land area, it usually identifies only the gross topographic form and geologic material. The *area* is apt to comprise several smaller component landforms at more nearly the scale of individual soil occurrence. Some terms, such as piedmont slope, or mountain, or intermontane basin, automatically imply large land areas with numerous major landforms and their yet smaller component landforms.

The second drainage system of *fanhead trenches* cross the alluvial fans from their origin in the mountain valleys and join the interfan-valley drainageways. They may also spill out onto the fan piedmont or may even reach the basin floor. The third major system of *onfan drainageways* originate as dendritic drainageways on alluvial fans or on the fan piedmont. All three major piedmont drainage systems reflect the periodic dissection and deposition cycles[25] that have so strongly modified the alluvial fans and fan piedmonts that their boundaries bear little relation to the occurrence of individual soils.

Fan Collar

Minor Holocene erosional events on a few mountain scarps and in some small mountain valleys have produced sediment that was carried barely beyond the piedmont angle to form thin small alluvial fans or a narrow band of coalescent thin fans on top of larger older alluvial fans in some special situations (cf., Hunt and Mabey, 1966, p. A97; Gile and Grossman, 1979, pp. 477-480, 723, 730, map unit 13MO). Such thin alluvial mantles are called *fan collars* here because they occur on and at the very top of a large alluvial fans or fan piedmonts where the latter abut a mountain front. The fan-collar alluvium buries an older fan surface which reappears a short distance downslope in the fashion the metaphorical collar covers a shirt. Fan collars are rare component landforms since Holocene alluvium washed from mountain slopes normally is carried across the large alluvial fans in fanhead trenches. The alluvium in the trench may be deposited as an inset fan or spilled out further downslope as a fan apron. A fan collar is a special case of a fan apron that occurs at the top of an alluvial fan rather than on the fan piedmont.

Erosional Fan Remnant

Most alluvial fans have been dissected (Fig. 7), leaving erosional fan remnants as component landforms standing above wash channels or inset fans. As discussed previously, it is the relict surface of the remnant summit and the remnant sideslopes that are particularly significant for soil survey because of their different ages, slopes, and probably, soils. Erosional fan remnants may occur in stepped sequences, with the highest remnant having the oldest relict summit and soil, as shown in Figure 8. Their sideslopes normally have younger and different soils.

[25] Periodic dissection of Pleistocene land surfaces and creation of new surfaces have been attributed to both tectonic uplifts and climatic changes. One scenario of fan building in the Basin and Range Province, that seems to fit soil genesis, was proposed by Huntington (1907) after field studies in central Asia: It holds that during moister pluvials vegetation stabilized the mountainous source areas (and the fans) and allowed storage of rock waste produced by concurrently increased weathering. During *transitions* to ensuing drier periods, the vegetation thinned and the rock debris *that had been made available* was eroded from the mountains and transported to lowlands where the heavily loaded streams deposited it as fans and stream floodplains. As the supply of rock waste from the mountains declined, or an ensuing moister period increased protective vegetation, the stream loads declined. This led to dissection of previously deposited alluvium.

Another theory calls for an equilibrium between coarse mountain waste deposited on the piedmont slope, and loss of weathered, comminuted alluvium from the older fan surfaces via onfan drainage systems (cf., Hunt and Mabey, 1966; Denny, 1967; Bull, 1964). This latter theory deemphasizes the prominent field evidence of periodic, wholesale erosion or deposition in localized areas while other local areas enjoy long-term stability.

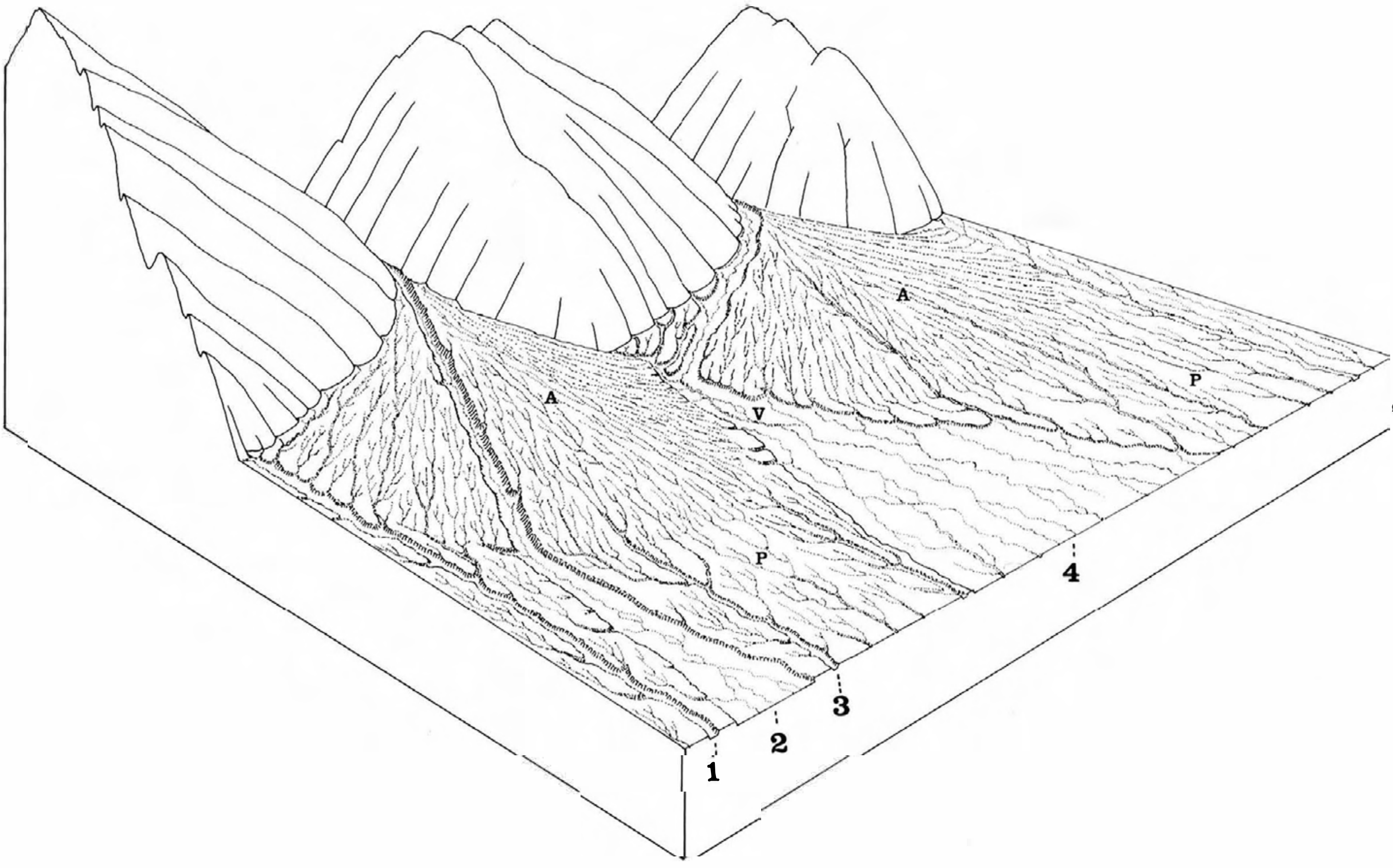


Figure 7. Two dissected mountain-front *alluvial fans (A)* bounding an *interfan valley* (the triangular part of the fan piedmont between the two fans) *(V)* that is occupied by an inset fan, and examples of the three major piedmont slope drainage systems: an *interfan-valley drainageway* with onfan tributaries *(1)*, a *fanhead trench* that broadens as it crosses the fan piedmont and has a few onfan tributaries *(2)*, an *onfan drainageway* that has numerous onfan tributaries originating both on the alluvial fan and fan piedmont *(3)*, and a broadly debouching *interfan-valley drainageway* that has both fanhead trench and onfan tributaries *(4)*. Note that onfan drainageways may rise on any major landform or component landform.

Fan-Remnant Summit—The summit landform element of erosional fan remnants may occupy somewhat less area than the sideslope element where dissection is close and remnants small. They may also be much more extensive than the sideslopes where dissection is widely spaced (cf., Fig. 8 and 15). Summits are relict areas in that they have been little affected by erosion since fan dissection. Shallow onfan drainage systems eventually develop on summit areas but soil truncation is so slow that the summit soils ordinarily remain effectively older and different than the sideslope soils. Some fan remnants with broadly rounded shoulders have had their sideslopes stabilized so long ago that the summit and sideslope age differential has become unimportant. In these situations, very similar and strongly horizonated soils can occur on both landform elements, i.e., they approach the condition of old ballenas.

Summit areas are protected from alluvium deposition because the drainage systems that might spread the alluvium are incised. Summits can accumulate eolian dust (loess) and have in most desert areas. There is some evidence that, in Nevada, shallow erosion in small spots connected to onfan drainage systems has partially stripped eolian mantles and truncated the A horizon of some summit soils (Alexander and Peterson, 1974, p. 16, Fig. 4), but not enough to change the soil's identification. The area of summit landform elements is primarily reduced by the sideslopes wearing back.

Fan-Remnant Sideslopes—The sideslopes of erosional fan remnants (Fig. 8) are identified as a separate landform element because they are apt to be significantly younger than the summit, to have different soils, to have much steeper slopes, and because they are liable to be recently eroded. The sideslopes of most erosional fan remnants on the piedmont slopes form digitate margins along irregular spurs that branch off a main trunk. The spurs reflect gullying into the sides of the remnants. They in turn may be cut by rills and gullies. The entire sideslope margin of some remnants is rilled, eroding, and reducing the summit as it wears back. But more commonly, active erosion is limited to a few sideslope segments along the remnant margin. Other segments have been stable long enough to have pedogenic soils. As noted above, some remnants with broadly rounded shoulders have similar, stable, pedogenic soils on both summit and sideslope. The sideslope is part of an erosion surface that has distinctive morphogenetic parts called slope components.

Slope Components—A fan-remnant sideslope has *shoulder* and *backslope components,* and may have a *footslope component* (cf., Fig. 15). When actively eroding, the shoulder and backslope wear back into the remnant. The backslope is concave in its lower part and may or may not have a straight upper part. In a few situations of shallow or recent dissection, the convex shoulders may reach nearly to the flanking channel with only a short, straight backslope between them (Fig. 8-1). As the shoulder and backslope wear back into a fan remnant, a gentle, slighty concave footslope, or pediment, forms between the base of the backslope and the channel (Fig. 8-2) and has sediment transported across it. In this situation, the shoulder, backslope, and footslope surfaces (i.e., drainageway bottom) are effectively the same age. If the remnant sideslopes stabilize, and the drainageway then alluviates, or back-fills with sediment from higher reaches, an inset fan is formed in the drainageway and its surface is younger than the sideslope. The footslope is now buried (Fig. 8-3). Or, segments of the sideslope may continue eroding and contributing sediment to the inset fan as it is desposited. Consequently, both these surfaces would be the same age. Erosional slopes are discussed further on p. 36 *et seq.* There the term pediment is explained as an alternative name for the footslope component and an additional component, the toeslope, is identified. Toeslopes are lower portions of footslopes that have accumulated a significant alluvial mantle. On the piedmont slope, such toeslopes would be part of an inset fan, fan apron, or fan skirt, and therefore are not identified.

Partial Ballena—Where the sideslopes of a spur attached to a fan remnant, such as those shown in Figures 8 and 9, have retreated until their shoulders have joined in a narrow crest, the spur is called a partial ballena. This landform element differs from an ordinary ballena in that it is attached to a fan remnant with an older summit area of relict surface. Also, the soil of the partial ballena is apt to be contrasting to the summit soil, whereas the soils of ballena sideslopes and crests are apt to be like or similar. Partial ballenas are most common where a fan has been deeply or closely dissected as along major drainageways or on the lower parts of a dissected fan piedmont in a semi-bolson. The term *partial ballena* is an alternative name for a particular part, or form of a fan-remnant sideslope.

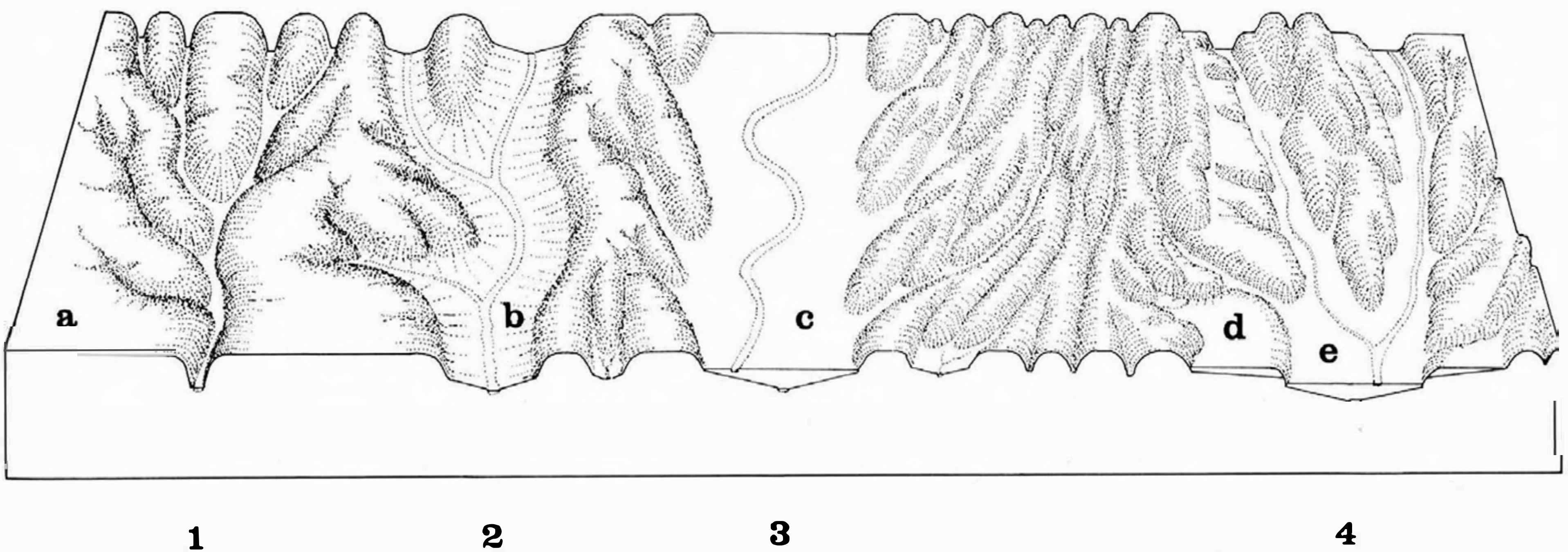
Channels—Channel landform elements are ordinarily barren and composed of variously sorted stream alluvium, bars, and dumps of stones or cobbles that are evidence of recent flooding along well defined to braided streams. They may be enclosed between walls, as when related to fan dissection, or may be splayed across and slightly mounded above a fan surface as when related to fan apron construction. Channels are classed as landform elements, but they may or may not occur on or next to the landforms for which they are listed in Tables 1 and 2. Also they may or may not be geneticlaly related to those landforms.

Inset Fan

An inset fan is a special case of a floodplain—commonly, of an ephemeral stream[26] floodplain—that is *confined between fan remnants, or basin-floor remnants, or ballenas, or the very closely spaced toeslopes of two alluvial fans* (as in an interfan valley) *or fan piedmonts* sloping together from opposite sides of a narrow basin (Fig. 4, 5, 10, 12). It has a transversely nearly level surface *broad enough that barren channels cover only a minor part of its surface.* The remainder is ordinarily vegetated. Its transversely level surface indicates that it is an aggradational, or constructional landform (Fig. 8-3). A similarly broad drainageway incised below fan remnants, but not aggraded, would be expected to have a cross section showing a transversely gently sloping bottom (i.e., pediments leading down from the fan-remnant backslopes to

[26]An *ephemeral stream* flows briefly in direct response to local precipitation and is well above the water table. An *intermittent stream* flows seasonally from surface flow or springs. A *perennial stream* flows throughout the year and its surface is apt to be somewhat lower than the water table in the adjoining alluvium.

Figure 8. Diagram of a transverse segment of a dissected fan surface illustrating the common sequence of *dissection alluviation, redissection, realluviation, etc.*, that produces different age erosional and constructional surfaces on the piedmont slope. In cycle *1* the original, constructional fan surface has been dissected by a narrow gully system, thus forming erosional fan remnants with flattish relict-surface summits *(a)* and relatively young erosional sideslopes that are the same age as the channel if they are actively eroding. Along drainageway *2* the sideslopes have retreated by erosion and a footslope *(b)*, or pediment, has formed which is the same age as the sideslope. Drainageway *3* has been alluviated, or aggraded, and an inset fan *(c)* formed whose surface may be younger than the sideslopes if they have stabilized and the alluvium is from higher on the piedmont slope, or its surface may be the same age if the sideslopes are actively eroding or if both surfaces stabilized at the same time. Between drainageways 3 and *4* the fan remnants have been reduced to mostly partial ballenas. Along drainageway *4* a second cycle of dissection has cut the inset fan, leaving inset-fan remnants *(d)*, and the pediments of that second erosion cycle have been buried under a yet-younger inset fan *(e)* formed by a second cycle of alluviation.



the fluve channel, Fig. 8-2). An inset fan may be the same age, or younger, or somewhat older than its bounding remnant sideslopes. However, it is younger than any relict-fan surface above it and is most commonly younger than any bounding ballena slopes (cf., Ruhe, 1967, p. 25).

These alluvial fills have not been called floodplains for several reasons: Downslope they commonly debouch to form coeval fan aprons or fan skirts. The boundary between the inset fan and fan apron or fan skirt is merely the terminus of the walls bounding the inset fan and similar names seem preferable. The inset-fan alluvium ordinarily is indistinguishable in kind from that of a contiguous fan apron or fan skirt, or even from that of the bounding fan remnants. The generic term *fan* in all these landform names suggests their similar alluvium and genesis. And last, where an inset fan is trenched, its flattish topped remnants seem most reasonably grouped with alluvial-fan remnants, fan-piedmont remnants, fan-apron remnants, and fan-skirt remnants as parts of stepped sequences of fan remnants in general that occur on the piedmont slope (Fig. 8-4). Alternatively, if the inset fan were called a floodplain, its erosional remnants would have to be called "stream terraces" or "alluvial benches," though only difficultly distinguishable from other fan remnants.

Most inset fans of desert basins seem to have been built by ephemeral streams. Their alluvium is apt to be only crudely sorted and cut by gully fills, though in some basins it may be loamy material contrasting with the extremely gravelly bounding fan remnants. In mountain valleys and on the upper piedmont slope, intermittent or perennial streams may flow in narrow valleys containing inset fans; discontinuous wet meadows and phreatophytic vegetation may occupy these mesic inset fans.

Inset fans are probably most extensive on dissected fan piedmonts, but they also are significant component landforms within dissected alluvial fans and mountain-valley fans, and between ballenas and basin-floor remnants. Their distinctive topographic position and soils make them easily recognized features for finding soils and landforms in the field and for describing soil associations.

Fan Piedmont

The largest and most extensive major landform of the piedmont slope is the *fan piedmont* (Fig. 3). This name is a contraction of the similar terms *coalescent-alluvial-fan piedmont* and *alluvial-fan piedmont*. Both imply that the fan piedmont is the joined lower slopes of adjacent mountain-front alluvial fans[27]. It is that, of course, but only in gross topographic and genetic senses. Aerial photos of most fan piedmonts show they are comprised of *numerous, triangular or elongated-diamond-shaped alluvial mantles and fan remnants*. The alluvial mantles issue individually from fanhead trenches, interfan-valley drainageways, and onfan drainageways rather than being mere undifferentiated extensions of alluvial fans. (Such complex fan piedmonts are also called *segmented alluvial fans*, cf., Cooke and Warren, 1973, p. 181 *et seq.*). In the classification given here, the different age mantles and remnants *that compose the area* of the fan piedmont are called *component landforms* and include erosional fan remnants, nonburied fan remnants, fan aprons, and inset fans. Most writers describe the fan piedmont as extending from the prominently semiconical alluvial fans down to the basin floor. For soil survey, however, this ignores the significantly younger and smoother fan skirt that occurs along the lowermost piedmont slope in many basins. The fan skirt is recognized here as an additional major landform. The fan piedmont is considered to end at the fan skirt, if there is one, or to extend to the basin floor if there is not one.

The provenance of alluvium along any reach of a fan piedmont is the alluvial fans immediately upslope and one or only a few mountain valleys. Therefore, the lithology of the fan piedmont directly reflects bedrock geology in the mountains. Fan piedmonts are built of sheet-like alluvial mantles that are only a few feet thick. Where the source materials were of mixed particle sizes, the strata forming the mantles tend to be very gravelly at their base and become finer upwards, grading to low-gravel loamy materials. Some late-Pleistocene alluvial mantles, however, seem to have been extremely gravelly or fragmental throughout. Their present soil zone has been made somewhat loamy largely by dust infiltration. The alluvial strata also may contain paleosols (buried pedogenic soils) that represent periods of stability of the land surface between periods of active deposition.

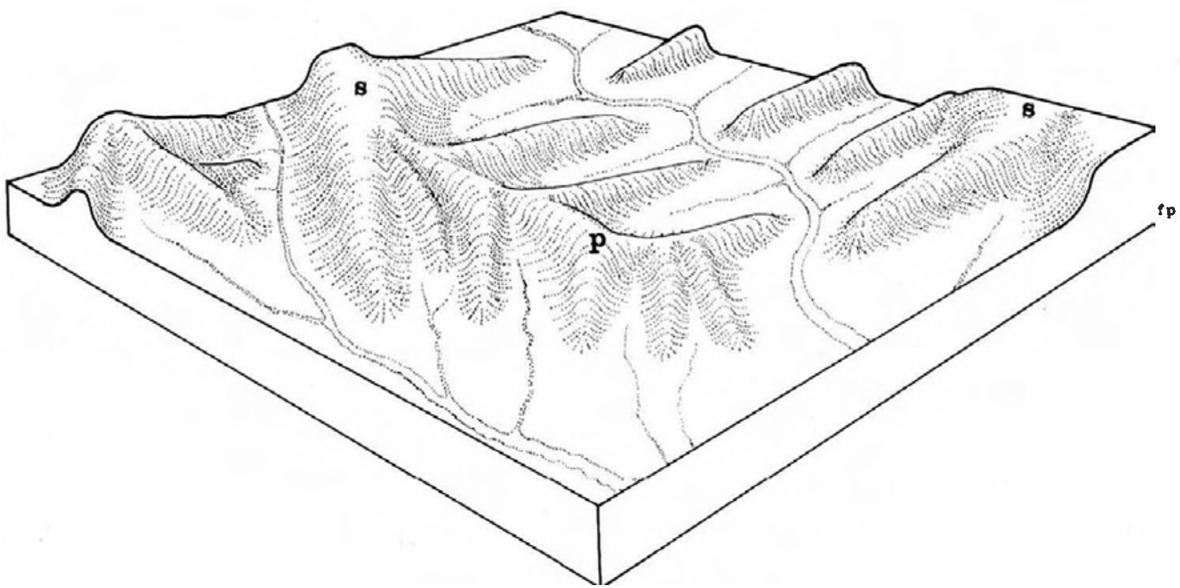
Fan piedmont construction can be pictured as deposition of such successive, overlapping, or imbricated, alluvial mantles during the Pleistocene and Holocene epochs[28]. During any one deposition interval, the individual thin alluvial mantles are emplaced along broad swales on the piedmont slope. Along the central part of these broad drainageways, active arroyo cutting and filling is reflected by channel zones, some tens or hundreds of feet wide, where the basal alluvium is most gravelly and best stratified. Upwards, it fines and is only weakly stratified. The mantle extends laterally for up to thousands of feet as a few-feet thick, fairly uniform deposit like that in the upper part of the channel-zone deposit. The mantle rests on the only slightly eroded, preexisting fan surface. As each sheet-like mantle fills a broad swale, the locus for succeeding mantles is shifted laterally across the fan piedmont (Hawley, 1980). Today's fan aprons represent only the latest interval of such deposition on the fan piedmont due to erosion somewhere upslope. Each of the contiguous or imbricated mantles deposited during the Pleistocene is a different age, but collectively the portions of the fan surface they form are all so old[28] that their soils have relict features reflecting past Pleistocene climates. Therefore they are collectively called *relict* fan surfaces.

These relict fan surfaces ordinarily occur as the summits of erosional fan remnants or as nonburied remnants between Holocene fan aprons. A few intermontane basins, however, contain very large remarkably preserved areas of Pleistocene fan piedmonts. Such relict surfaces may extend over hundreds of acres, are cut by few drainageways, and approximate the width of the fan piedmont. Reference to them as a single landform is most descriptive of the situation where their soils occur. Thus,

[27]Additional synonyms for fan piedmont that have been used include alluvial fan, segmented alluvial fan, fan, bajada, piedmont slope, and simply, piedmont.

[28]Hawley (1980) estimates the duration of the Holocene epoch as from the present back to 10,000 yr B.P., late-Pleistocene from 10,000 to 250,000 yr B.P., mid-Pleistocene from 250,000 to 900,000 yr B.P., and early-Pleistocene from 900,000 to 2,000,000 yr B.P.

Figure 9. A very small part of a strongly dissected fan surface showing *partial ballenas (p),* or fully rounded spurs, attached to fan remnants still broad enough to have some *relict summit area (s)* at their centers. Partial ballena is an alternative term for the sideslope landform element of erosional fan remnants when it forms a spur.



phrasing such as "these soils are on a slightly dissected, relict fan piedmont" draws attention to the preservation of a large, smooth, relict area, whereas a statement "the soils are on fan remnants" suggests smaller component landforms bounded by erosional scarps or fan aprons.

Erosional Fan Remnant

The same features described for erosional remnants of alluvial fans (cf., p. 18 *et seq.*) and for fan remnants in general (cf., p. 6 *et seq.*) apply to those of fan piedmonts. They have the same summit, sideslope, and partial ballena landform elements, and the crest, shoulder, backslope, and footslope components also are identified.

One new factor in remnant identification does appear on fan piedmonts: both *erosional* and *nonburied fan remnants* occur and not all can be identified or mapped with mutual exclusivity. A fan remnant may be scarped by erosion on one side and buried by a young fan apron on the other side. It has features of both types of remnants, and must be identified simply as a "fan remnant."

Inset Fan

The inset fans of fan piedmonts have the same features as those elsewhere on the piedmont slope (cf., p. 20 *et seq.*). They may originate in mountain valleys, on alluvial fans, or on the fan piedmont itself. Those originating upslope may debouch to form fan aprons or cross the fan piedmont and debouch as fan skirts. Inset fans rising on the fan piedmont may debouch as fan aprons or as a fan skirt below the fan piedmont.

Fan Apron

This component landform is a sheet-like mantle of relatively young alluvium comprised of a single stratum, or only a few poorly differentiated strata, which somewhere rests on top of a paleosol that can be traced to the edge of the mantle. There the paleosol emerges as the land-surface soil. The critical features of fan aprons are diagrammed in Figure 10. There can be no paleosols *within* the fan-apron mantle, but a pedogenic soil commonly does occur at its surface, though one need not occur (i.e., the "soil" is an Entisol). Therefore a fan apron represents a geomorphically significant depositional event that has created a *new* geomorphic surface. Beyond the edges of the fan apron, the preexisting land surface and soil are a *relict surface* and *relict soil* on a nonburied fan remnant.

Fan aprons are deposited below gullies or below inset fans as a continuation of their alluvial fill. Therefore they are genetically related to the erosion event that cut or extended the gully system, or that aggraded the trench in which the inset fan was deposited. The gullies may be cut into the fan piedmont or into alluvial fans upslope. The inset fans may originate on the fan piedmont, on alluvial fans, or within mountain valleys. A fan apron may be deposited in front of a single gully or inset fan, or it may be a coalescent mantle from several drainageways (cf., Ruhe, 1964, p. 149; 1967, p. 25).

A relict fan-piedmont surface or closely spaced erosional remnants of that surface *must occur downslope from a fan apron.* This requirement distinguishes fan aprons as a component of the fan piedmont, and allows separation of the very similar fan skirt as a distinct major landform (cf., Fig. 10, 12). Where remnants of the older fan piedmont occur downslope only as closely spaced erosional remnants, the alluvium of the fan apron may extend between them as inset fans and coalesce as it reappears to form a fan skirt. Where the erosional remnants are widely spaced, and the relatively young alluvial mantle continues on down to the basin floor as a laterally extensive area, the entire deposit is most simply called a "fan skirt with a few included fan-piedmont remnants." Like the erosional and nonburied fan remnants, all examples of fan aprons and fan skirts cannot be mapped with mutual exclusivity.

Fan aprons have a variety of planimetric outlines. Those formed by coalescence of alluvium from many sources are relatively wide, parallel to the mountain front, and short down the piedmont slope. These best fit the metaphor of an apron that covers part of the fan piedmont, but does not reach to the basin floor. Many others, perhaps most, follow a broad swale and are elongated down the piedmont slope. Though fan aprons are listed as a component of the fan piedmont, a few also occur on alluvial fans.

Nonburied Fan Remnant

Nonburied fan remnants are Pleistocene fan surfaces bounded by younger fan aprons, as described above and diagrammed in Figure 10. These remnants lack the erosional scarps of erosional fan remnants, but as described above, one type of remnant may merge with the other in some situations (cf., Fig. 10). Since the most important feature of both types of remnants is their relict fan surface, they ordinarily are called merely fan remnants (cf., p. 6 *et seq.*). Nonburied fan remnants may be an extensive component landform on slightly dissected fan piedpiedmonts, or may be absent from closely dissected ones. They are distinguished from erosional remnants primarily to help establish the stratigraphy of the fan aprons and to rationalize the soil patterns associated with fan aprons.

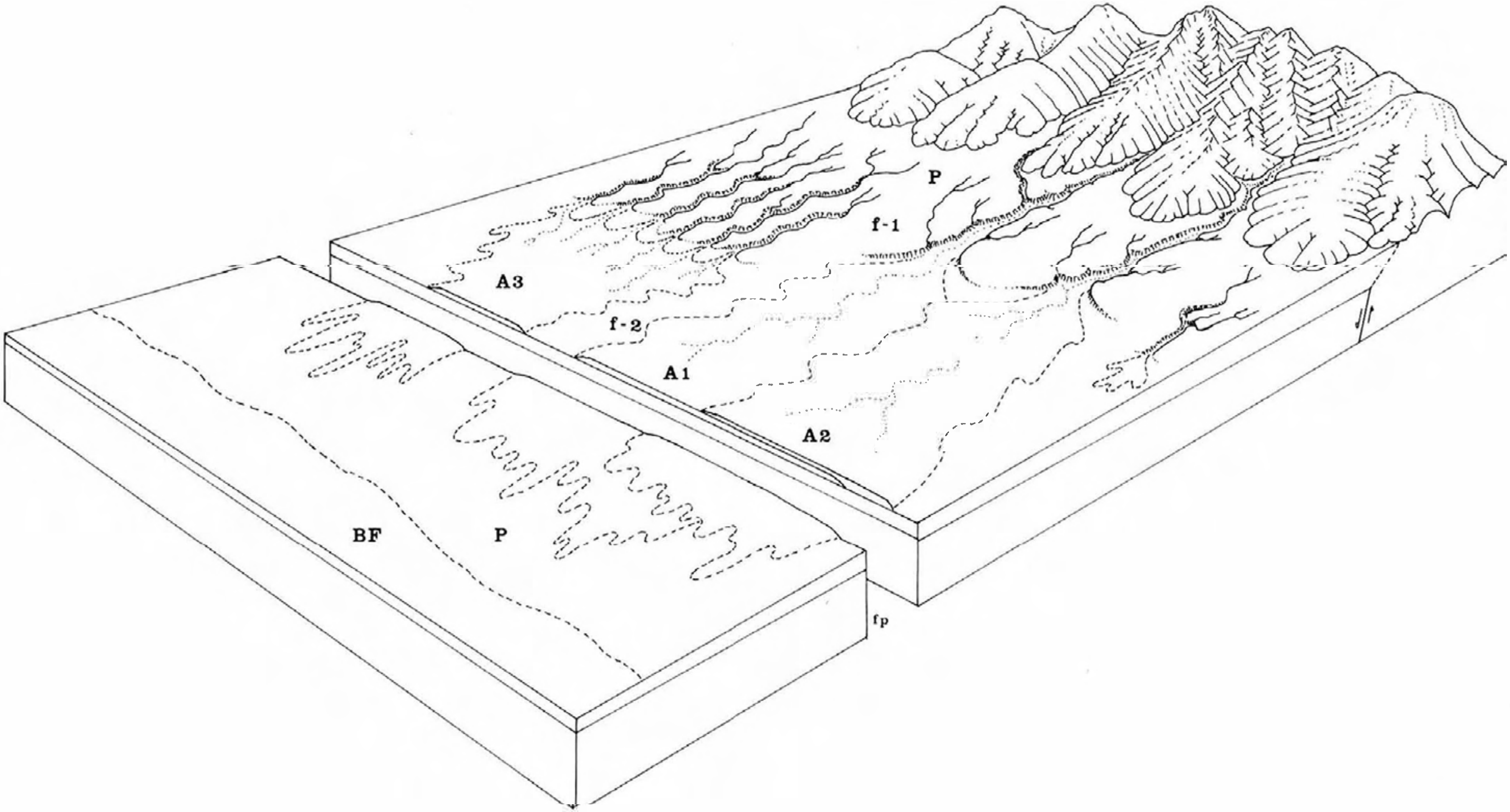
Beach Terrace

Beach terraces are narrow, long component landforms cut into fan piedmonts and fan skirts by the waves of Pleistocene lakes during still stands. They consist of an upper, fairly steep, wave-cut scarp, and a flattish, wave-built terrace of sorted, clean gravel and sand above a gentle lower scarp. The upper scarp may be lacking on gentle fan slopes. Successive beach terraces are separated by remnantal fan slopes. The upper foot or so of beach gravel ordinarily is infiltrated with eolian dust, or the beach terrace and remnantal fan slope between terraces may be mantled with eolian material. Beach terraces are younger than the constructional fan surfaces they are cut into. In places, old beach terraces may be dissected or buried under the younger alluvium of a fan apron. On some piedmont slopes, receding lakes cut numerous beach terraces, whereas only one or a few occur on others. Unless the basin has been tectonically deformed, the terraces follow a contour. They may be absent from reaches along the piedmont slope where little wave action occurred.

Pediment
(On Unconsolidated Alluvium)

A pediment is the gentle slope left at the base of a steep backslope as the backslope is cut farther and farther into a highland mass or fan remnant by erosion. The general

Figure 10. A schematic diagram of *fan aprons (A)* on a *fan piedmont (P)*. Note that the *relict fan piedmont surface occurs both above and below the fan aprons*, separating them from both the mountain front and the *basin floor (BF)*. Fan apron *A1* is younger than the relict fan-piedmont surface because it overlies it, but is older than fan apron *A2* because it is buried by *A2*. Fan apron *A3* was formed by lateral coalescense of several small fans from onfan drainageways, whereas fan aprons *A1* and *A2* are individual mantles debouching from fanhead trenches and would be considered of significantly different ages if a pedogenic soil of *A1*-age is buried by fan apron *A2*. Fan apron *A3* is younger than the relict fan-piedmont surface, but may be either younger, older, or the same age as the other two fan aprons. Also, note that the fan-piedmont remnant at position *f-1* is an "erosional" remnant (i.e., is scarped), whereas at position *f-2* the same relict surface is a "nonburied" remnant; these distinctions are merely heuristic.



term *pediment* is a synonym for the *footslope component* of an erosional sideslope and includes footslopes cut from either unconsolidated alluvium or bedrock[17]. But here the latter are specifically identified as *rock pediment* and listed in Tables 1 and 2 as a separate major landform of the piedmont slope. Therefore, when the lone term *pediment* is used in the context of piedmont slope landforms, it implies that the pediment has been cut from unconsolidated alluvium. The term *pediment* (major landform) is used, rather than *footslope* (slope component) only when this erosional landform is an *extensive enough* part of a dissected fan piedmont that it no longer appears to be a minor part of an erosional fan remnant. Such a prominent pediment is treated as a major landform of the piedmont slope because of its special erosional history, as is the ballena, and because pediment remnants seem comparable to many fan-remnant component landforms.

The footslopes of fan remnants on most dissected fan piedmonts have minor extent either because the drainageways are narrow or because the drainageways have been aggraded and their footslopes buried under inset fans (cf., Fig. 8-1 and 8-3). On some dissected old fan piedmonts, however, backslopes that originated as gully walls have worn back so far into the fan remnants that most or all of the relict fan summits have been destroyed and their former area replaced by pediments, as illustrated in Figure 11. In this sort of situation, where pediments and pediment remnants about equal or exceed the extent of summits of fan remnants, the term pediment draws attention to the extent of erosional surfaces and the genesis of the landscape. Similarly, in some semi-bolsons, such as parts of the upper Humboldt River drainage, successive pediments have been cut across sometimes faulted and tilted Tertiary basin-fill sediments that are only weakly consolidated. These pediments form a slope that looks much like a dissected fan piedmont, but has a different genesis.

Pediment Remnant (On Unconsolidated Alluvium)

Several cycles of dissection by gullying and backslope retreat have occurred in most situations where pediments are extensive enough to be identified on fan piedmonts (Fig. 11). If the drainageways were not aggraded before being gullied by a new erosion cycle, *pediment remnants* rather than inset-fan remnants are left as benches along the drainageway flanks. These are distinguished by their gentle summit slope toward the incised drainageway, as compared with the nearly level transverse section of the summit of an inset-fan remnant. Similarly, a pedimented summit formed by opposed backslopes retreating until they join and disappear (cf., Fig. 16 and 11-c) can be distinguished from a transversely nearly level relict fan surface by the gentle slopes towards the drainageways. Where a pediment merges with a relict fan surface, the whole summit is transversely asymmetric (Fig. 11-b). Exposures of erosionally-planed sediments that are angularly unconformable to the land surface also are clues to help distinguish pediments from constructional fan surfaces.

A pediment remnant on unconsolidated alluvium, like a fan remnant, must have some relict *summit* area (except it is a relict pediment surface) and has a *sideslope* comprised of *shoulder, backslope*, and *footslope* slope components. If wide enough, the footslope may be called the next younger pediment. When the shoulders of a pediment remnant meet by sideslope-backwearing, and the summit is reduced to a crest, the remnant is called a ballena. It is not always necessary to distinguish all pediment remnants from fan remnants for soil mapping, since both are formed of fan alluvium. Also, in stepped sequences, the same rule holds for both that the highest remnants have the oldest relict summits and soils.

Fan Skirt

A fan skirt might be considered a component landform of the fan piedmont, rather than a major landform, since it is merely an extension of the gross zone of coalescing fan alluvium that parallels the mountain front. The fan skirt, however, is considered a major landform here because of its distinctively smooth topography, its lack of dissection relative to the fan piedmont, its relative youth, and its distinctive position in intermontane basins[29].

A *fan skirt* is a belt of gently sloping, coalescent alluvial fans[30] issuing from gullies and inset fans of a dissected fan piedmont and *merging with the basin floor* along their lower boundary, as diagrammed in Figure 12. Segments of a fan skirt derived from different drainageways may differ lithologically and be somewhat different ages. The fan skirt is undissected or its channels are only very slightly incised. Its drainageway bottoms are fully occupied by their active channels. The fan skirt, therefore, is among the younger fan surfaces, along with fan collars, inset fans, and fan aprons. Fan skirts comprise the topographically smoothest zone on most piedmont slopes. They are apt to be composed of nongravelly, or only fine gravelly, loamy alluvium with an original provenance in the mountains upslope. The soils of fan skirts may have excellent agricultural potential because of their texture, gentle slope, lack of dissection, extensiveness, and because they are still above the most probable areas of soluble salt accumulation on the basin floor.

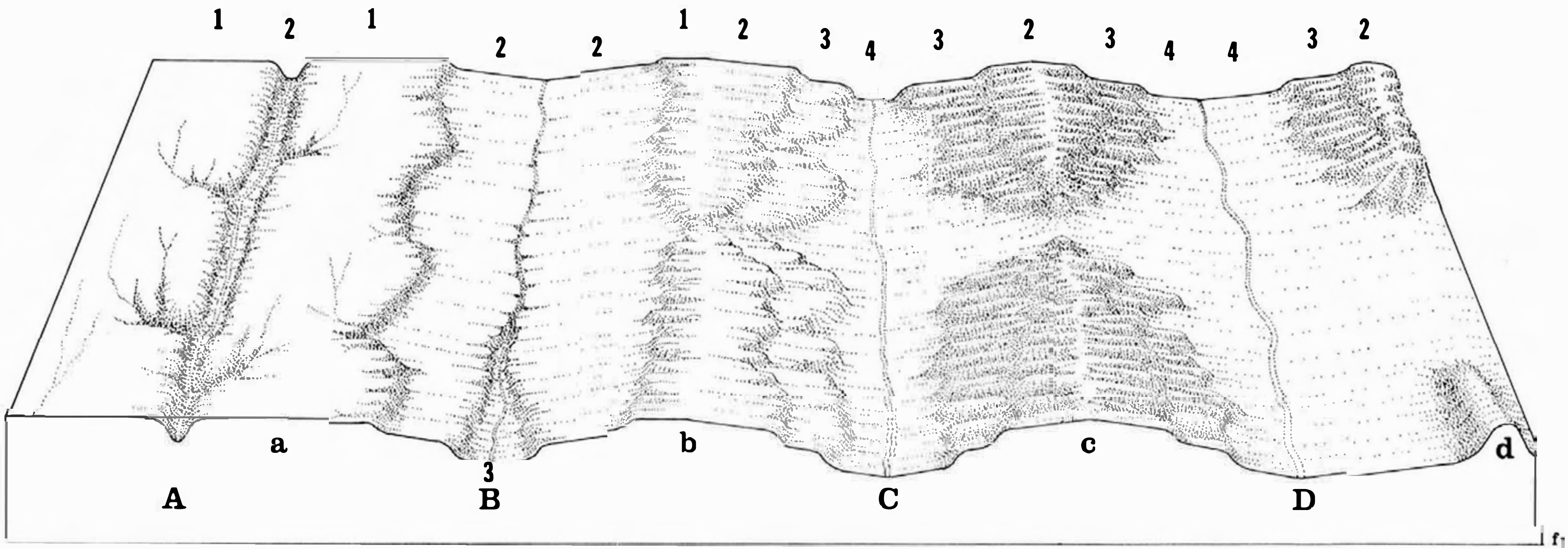
Fan skirts may be thin and only a few hundred yards long downslope, or they may be a mile or more long. They may be composed of raw alluvium, or they may have been stable long enough to have pedogenic soils. Some fan skirts are deep and extend far back toward the mountain front. These are apt to include a few outlying remnants of the fan piedmont and some dissected areas. The boundary of the fan skirt with the basin floor is indistinct topographically, but it can be approximated as the line along which drainageways from the piedmont slope turn or meet those of the basin floor that parallel the mountain front.

Narrow *beach terraces* occur on the fan skirts of some bolsons (cf., p. 24). These, ephemeral stream *channels*,

[29] Hawley (1980) suggested *alluvial slope* as a very general term for the very gently inclined, lowermost piedmont slope component, or toeslope, that lacks the transverse convexities imparted to the upper fan piedmont by individual-fan sources of alluvium. This is basically a topographic definition and lacks the inferences of relative surface age of the fan skirt concept.

[30] The dissected fan piedmont of some semi-bolsons extends almost to the axial-stream floodplain. Small *fanlettes* issuing from its drainageways spill out onto the floodplain—or onto a stream terrace, if the axial floodplain has been recently gullied—and barely coalesce as a skirt, or are separate.

Figure 11. A transverse segment of a *pedimented* fan piedmont that slopes toward the viewer. Along drainageway *A* the original fan surface *(1)* has been dissected by a single gullying cycle, leaving short pediments *(2)*, or footslopes, flanking the gully channel. Along drainageway *B* the fan has been dissected by two gully erosion cycles, and their retreating backslopes have left pediments *2* and *3* behind them. A third erosion cycle has dissected drainageways *C* and *D* leaving pediment *4* behind its retreating backslopes. Divide *a* is transversely level and comprises only the relict fan-piedmont surface *(1)*. Divide *b* is asymmetric and comprises pediment *2* merging with the relict-fan surface *(1)* after complete retreat of the backlope of pediment *2*. Divide *c* comprises ridgeline remnants of pediment *2* and *3*, and in the middle ground, a pediment pass fromed by mergence of the backslopes of pediment *4*—as they retreated from drainageways *C* and *D*—and destruction of the intervening ridgeline remnant. Divide *d* comprises a ridgeline remnant of pediment *2*, a pediment pass (*4*-surface), and other remnants of pediments *2* and *3* in the background. Along divide *c*, pediments *2* and *3* are represented by only ridgeline remnants (i.e., ballenas), whereas along divide *b* the same age pediments are represented by pediment remnants with preserved, relict-surface summits. This diagram illustrates backslope retreat first parallel to major drainageways, and then parallel to tributary gullies on the sides of divides *c* and *d*. Other pedimented areas may have ovate or irregular outlines, rather than the prominently rectilinear outlines of this hypothetical illustration.



occasional *sand dunes,* or *sand sheets,* and a few fan remnants are the only differing components included within fan skirt areas.

Basin Floor (Bolson Floor)

Two major landforms dominate most of the generally smooth and nearly level floors of bolsons. One is the barren, ephemerally flooded playa. The other is the vegetated alluvial flat (Fig. 3). Bolsons that contained pluvial lakes commonly have relict lacustrine landforms and related eolian landforms over part of the area that otherwise would be an alluvial flat.

Alluvial Flat

The alluvial flat extends from the toeslope of a fan skirt (or fan piedmont, if there is no fan skirt) to the playa of a bolson or to the axial-stream floodplain of a semi-bolson, exclusive of other landforms such as lake plains, beach plains, and sand sheets. It is a nearly level, graded surface built of sediment carried by sheet floods or by broad, intricately-braided, ephemeral streams. The alluvial flat is the nearly level part of a basin where sediment that has been moved down the piedmont slopes, at about right angles to basin's long axis, is apt to be mixed with sediments from various reaches of the piedmonts as it is now moved parallel to the long basin axis on its way to the playa or out of a semi-bolson (Fig. 2, 3) (Hawley, 1980). The alluvial flat is apt to be the most extensive major landform of a basin floor, even though eolian and lacustrine landforms may have been superimposed on former parts of the alluvial flat. Extensive areas of either recent (i.e., Holocene) or relict Pleistocene alluvial-flat surfaces may occur in a basin.

Relict Alluvial Flat

This component landform is comprised of Pleistocene age portions of an alluvial flat that occur either where Holocene sediments have been confined to shallow drainageways, on their way across the flat, or where post-pluvial discharge of sediment onto a basin floor has been too little to mantle the entire Pleistocene alluvial flat. A few alluvial flats have been warped or broken by faulting. These may be shallowly dissected, leaving low erosional remnants with relict summits. These sorts of relict surfaces are direct analogues to the relict fan remnants of the piedmont slope. They are somewhat differently named to emphasize their location on the basin floor and because they are less commonly, and less prominently, if at all scarped by erosional slopes than are erosional fan remants.

Recent Alluvial Flat

This component landform is comprised of the Holocene age portions of an alluvial flat. (The adjective *recent* is used as a synonym for Holocene and includes *modern* surfaces, such as those with evidence of current sediment deposition.) It is an analogue of the fan apron and fan skirt. A recent alluvial-flat component may overlap and merge with a relict component with little or no topographic expression, or may be slightly inset against the relict component. Therefore recent alluvial flats must be defined in a negative sense as surfaces for which there is no clear evidence of relict Pleistocene status, such as soils with argillic or calcic horizons. Thin natric horizons can occur on Holocene surfaces, and are not good evidence of Pleistocene age.

Alluvial Plain

This major landform is either the relict floodplain of a Pleistocene stream that crossed a broad basin floor, or the very low-gradient fan delta it built out onto a basin floor. It is distinguished from the more common alluvial flat by its well sorted, stratified sand and gravel and pebbles of foreign lithology, rather than by a topographic break. Examples of relict floodplains of the ancestral Rio Grande river occur on the La Mesa plain of southern New Mexico (Hawley, 1980), and of a fan delta where Pleistocene Hot Creek debouched into Railroad Valley, Nevada.

Sand Sheet

Where large quantities of sand were available from the pluvial lake beaches and beds of some bolsons, extensive sand sheets have been spread downwind across alluvial flats, onto piedmont slopes, and even onto and over low mountains (e.g., Desert Valley and Lahontan Desert, Nevada, and Dale Lake, Mojave Desert, California). Sand sheets are several feet thick, continuous, and may have undulating surfaces. They may also have been blown into dunes (the *dune fields* of some writers).

Sand Dune

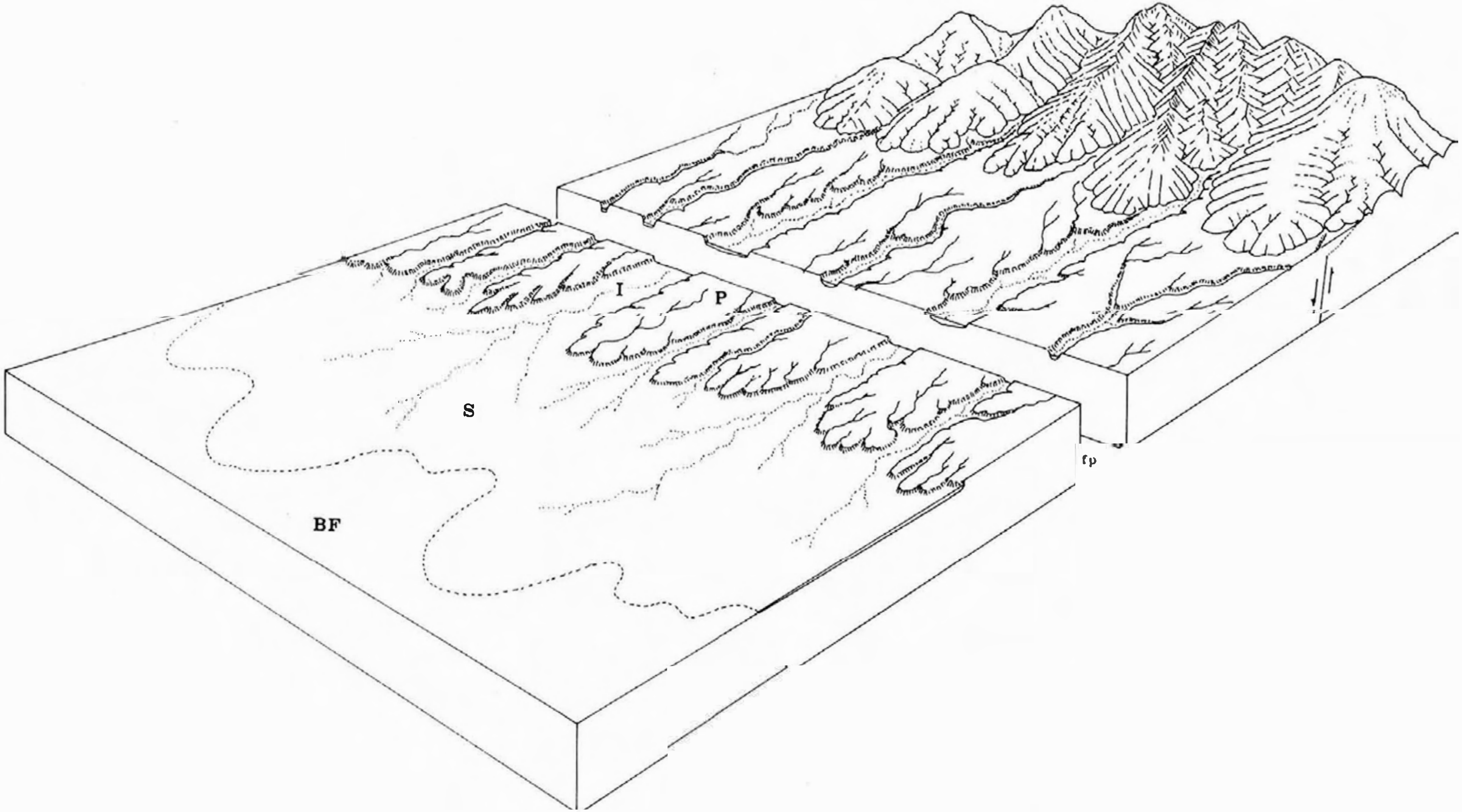
In other situations, individual sand dunes were built on alluvial flats and other landforms leeward of pluvial lakes in many basins. The sand may have blown from beaches, or from alluvial veneers deposited by ephemeral streams emptying onto dry-lake beds. Sand dunes are considered component landforms in that they may coalesce into sand sheets. Between closely spaced large sand dunes, *interdune flats* of basin-floor or piedmont-slope alluvium may be exposed. Some playas have *parna dunes* along their leeward margin. These are clay or clay loam textured dunes built of sand size aggregates blown off the playa.

Large volumes of *dust* (i.e., very fine sand, silt, and some clay and salt) also blew out of the desiccated pluvial lake beds and is blowing off of modern playas. Eolian dust has been a very significant factor in desert soil genesis, both as shallow loess mantles (e.g., the Humboldt loess belt, northern Nevada) and as fines infiltrated into coarse textured parent materials (Peterson, 1977). Eolian dust also has been the source of calcium carbonate, silicate clay, and sodium salts for desert soil genesis (Gile and Grossman, 1974; Peterson, 1980).

Beach Plain

The pluvial lakes that occupied many bolsons built prominent *barrier bars* and numerous *offshore bars* during recessional periods. Bars are component landforms that are elongate, level topped, commonly curving ridges of well sorted sand and gravel that stand above the general level of a bolson floor. Barrier bars are prominent dams that close off drainage from considerable parts of a basin. Offshore bars are less conspicuous ridges. The upper foot or so of most bars has been infiltrated and plugged or even thinly mantled by eolian dust. Pedogenic soils occur in this surficial zone infiltrated with dust and the immediately subjacent beach gravel. Behind the bars,

Figure 12. A schematic diagram of a *fan skirt (S)* that merges along its lower boundary with a *basin floor (BF)*, and that was formed by coalescing alluvial fans originating at gullies cut in a dissected *fan piedmont (P)* and by debouching *inset fans (I)* of the fan piedmont. The erosional fan-piedmont remnants and mouths of the inset fans form the upper boundary of the fan skirt. It is the same age surface as the inset fans, but is younger than the relict summits of the fan remnants. It may be the same age or younger than the basin-floor surface, but as shown here is younger because its alluvium overlaps the basin-floor surface.



drainage across the alluvial flat has been ponded in shallow depressions that are metaphorically called *lagoons*. Silty sediment is trapped there. Some bars have been breached by erosion and the lagoons drained. Others still trap ephemeral drainage and their lagoons are miniature playas.

Where recessional lakes have built closely spaced offshore bars with intervening lagoons across wide areas of former alluvial flats (e.g., Dixie Valley and Railroad Valley, Nevada), the resulting major landform is called a *beach plain*.

Lake Plain

The bottoms of the pluvial lakes were veneered and leveled with fine textured, nongravelly, stratified sediments. Where one of these relict lake bottoms is not occupied by a playa, it is called a *lake plain*. Some lake plains are comprised of two or more levels, or *lake-plain terraces*, separated by low scarps and formed by recessional stands of the lake. Lake plains are differentiated from alluvial flats—with which they may merge, if not separated by offshore bars—by the high silt and clay content of their well stratified sediments, as compared with the more sandy, occasionally gravelly and poorly stratified sediments of alluvial flats. Lake plains are vegetated and slowly drained whereas playas are barren and ephemerally flooded.

Playa

The playa, or nearly level dry lake of most bolsons is a sink where drainage water evaporates (Fig. 3). All playas seem alike, but they have considerable variation in materials, salinity, and hydrologic regimes. Playas are defined here as (1) areas on the *floor* of an intermontane basin that (2) are *barren of vegetation*[31], (3) are *ephemerally flooded*, and (4) are veneered with *nongravelly, fine textured sediment*. Most playas were once bottoms of pluvial lakes, but their boundaries are not necessarily coincident with those of the old lake beds. Their surficial sediments ordinarily are thin Holocene deposits rather than pluvial lacustrine sediments.

Pluvial lake beds (i.e., the area below the lowest offshore bars or beach terraces) are neither perfectly level, nor can most be filled by the runoff available under today's relatively arid climate. The part of the bed not intermittently flooded is at least sparsely vegetated and has pedogenic soils. It is the lake plain. Runoff collects in and shallowly floods the low parts of the old lake bed, or playa. The floods deposit a thin veneer of Holocene alluvium. This veneer may be a silt loam or silty clay, whereas the pluvial lake sediments are commonly clays. Near the margins of an old lake bed, deltaic sand or beach gravel may underlie the fine Holocene sediment.

The definiton of playas used here does not demand that they be the *final* sink for drainage. Nor does it exclude them from semi-bolsons. If a playa is the final sink in a bolson, then it is a major landform. Shallow ponds and fine sediment are, however, apt to collect as small playas behind minor runoff obstructions on a basin floor, such as offshore bars and fan skirts merging from opposite sides of a basin. These are also playas (or a lagoon, if behind a bar), but their scale is more that of a component landform. Miniature playas, or *playettes*, only a few feet in diameter, are common microtopographic features on many alluvial flat and piedmont slope soils. These vesicular crusted, barren spots are so small and so closely related to pedogenic processes that they are considered soil features rather than landforms.

Playa sediments are not necessarily saline, much less crusted with salts, as are the *salinas* of Mexico and elsewhere. Prominent soluble salt accumulation is most commonly associated with capillary groundwater discharge. Playas veneered with salt may remain moist, or they may periodically dry to hard crusts or soft puffs. Less salty playas regularly dry to form hard crusts that crack into polygons (Neal, 1965).

Floodplain Playa

Modern drainage moving along the low gradient, broad, axial drainageways of some bolsons and many semi-bolsons spreads widely behind minor obstructions to form *floodplain playas* that are very elongate or beaded alternately with ordinary narrow channel segments. The shallowly-spread drainage water deposits fine textured sediment on them that crusts as it dries. Floodplain playas are barren of vegetation, as are ordinary playas, except that they commonly are segmented by narrow, transverse bands of vegetation such as greasewood (e.g., Stonewall Flat and Lida Valley, Nevada, and Spring Valley, southwestern Nevada, near Mina). These are not final sinks, though much floodwater may evaporate before draining on off. Rather, they are part of an axial drainageway that feeds a final playa or drains a semi-bolson. They are classified as component landforms because they add to the total playa area of a bolson, and even though they act as and alternate with ordinary channel segments (cf., Fig. 14). They are "floodplain" playas inasmuch as floodwater spreads and deposits sediment on them.

Landforms of Semi-bolsons

Semi-bolsons differ from bolsons only because their floors ordinarily lack major playas and relict lacustrine landforms. Their piedmont slope landforms are so nearly like those of bolsons that they need no further discussion, but are repeated in Table 2 for emphasis. The floors of semi-bolsons may be as broad as those of bolsons, or they may be narrow and closely bounded by deeply dissected piedmont slopes. Some semi-bolsons are almost closed by encircling mountains cut by merely a bedrock gorge (e.g., Upper Reese River Valley, Nevada). Others open broadly into river valleys or into huge bolsons. The latter may even once have been occupied by arms of deep pluvial lakes, although they now drain externally (e.g., Desert and Kings River Valleys, Nevada). Yet others were once bolsons and have been partly drained by a deeply incised river valley, such as the Rio Grande valley. Contrawise, some desert basins once crossed by vigorous pluvial rivers now seldom yield drainage, although their landforms reflect past river dissection (e.g., White River and Kobe Valleys, Nevada).

[31] The lack of vegetation on playas is commonly attributed to extreme salinity. But, since some playas are nonsaline, salinity can not be the sole cause. Crusting prevents the emergence of many seedlings. Flooding for several weeks may kill any upland plants that establish. Prolonged drought should kill chance aquatic seedlings. Salinity, flooding, and resultant crusting are all functions of the landscape position of playas, hence barrenness is a reasonable landform criterion.

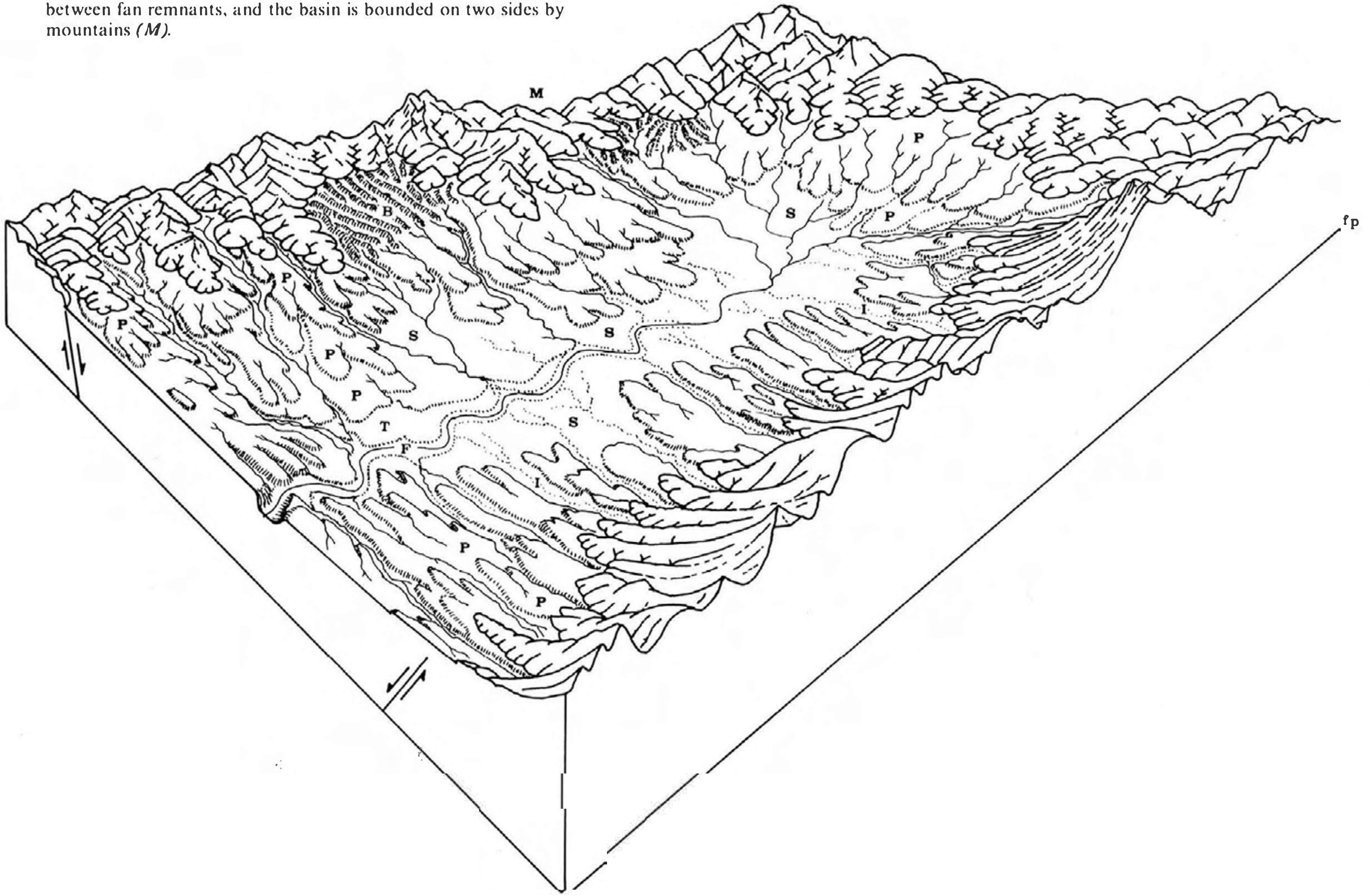


Figure 13. A semi-bolson that displays the effects of several cycles of dissection and deposition. The major landforms are: *ballenas (B)*, the *fan piedmont* (comprising several levels, or ages, of fan remnants) *(P)*, the *fan skirt (S)*, an axial stream *terrace (T)*, and an axial stream *floodplain (F)*. Alluvial fans are not distinguished from the fan piedmont. *Inset fan (I)* component landforms occur between fan remnants, and the basin is bounded on two sides by mountains *(M)*.

TABLE 2
CLASSIFICATION OF SEMI-BOLSON LANDFORMS

landforms			parts of landforms	
I Major Physiographic Part	II Major Landform	III Component Landform	IV Landform Element	V Slope Component
Bounding Mountains	(not defined)	. . .	. . .	. . .
Piedmont Slope	Mountain-Valley Fan	Erosional Fan Remnant	Summit[1]	
			Sideslope	Shoulder
				Backslope
				Footslope[2]
			Partial Ballena[3]	Crest
				Shoulder
				Backslope
				Footslope
			Channel[4]	
		Inset Fan	Channel	
	Rock Pediment[5]	Rock-Pediment Remnant	Summit, or	Crest[6]
			Sideslope	Shoulder
				Backslope
				Footslope
			Channel	
	Ballena	. . .	. . .	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
	Alluvial Fan	Fan Collar[5]	Channel	
		Erosional Fan Remnant	Summit	
			Sideslope	Shoulder
				Backslope
				Footslope
			Partial Ballena	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
	Fan Piedmont	Erosional Fan Remnant	Summit	
			Sideslope	Shoulder
				Backslope
				Footslope
			Partial Ballena	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
		Fan Apron	Channel	
		Nonburied Fan Remnant	Channel	

Piedmont Slope continued on next page

TABLE 2—Continued

landforms			parts of landforms	
I	II	III	IV	V
Major Physiographic Part	Major Landform	Component Landform	Landform Element	Slope Component
	Pediment[5]	Pediment Remnant[5]	Summit	
			Sideslope...........	Shoulder
				Backslope
				Footslope
			Channel	
	Fan Skirt	...	Channel	
Basin Floor	Alluvial Flat	Relict Alluvial Flat	Channel	
(Semi-bolson Floor)		Recent Alluvial Flat	Channel	
	Alluvial Plain			
	...	Basin-Floor Remnant[5]	Summit	
			Sideslope...........	Shoulder
				Backslope
				Footslope
			Partial Ballena	Crest
				Shoulder
				Backslope
				Footslope
			Channel	
		Inset Fan	Channel	
	Sand Sheet[5]	Sand Dune[5]		
	Axial-Stream Floodplain	Floodplain Playa	Channel	
		Stream Terrace[5]	Summit	
			Sideslope...........	Shoulder
				Backslope
				Footslope

[1]The summit landform element is synonymous with the summit slope component.
[2]A footslope alternatively may be called a pediment. The toeslope component is not listed because ordinarily it would be part of an inset fan, fan apron, fan skirt, or alluvial flat.
[3]The term *partial ballena* is an alternative name for the portion of a remnant sideslope which forms a spur.
[4]The channels associated with various landforms may be within or between them or absent.
[5]Not a common landform.
[6]A rock-pediment remnant may have either a summit or a crest.

Semi-bolsons have an *axial stream* crossing their floor and exiting from the basin, as shown in Figure 13. It may be a perennial, intermittent, or ephemeral stream. The *floodplain* may be narrow or broad. In some cases it is covered by wet meadow. Or, it may comprise a beaded string of *floodplain playas* and anastomosing channels (Fig. 14-1). *Stream terraces* are occasionally found along an axial stream. These may be underlain by clean, well sorted and stratified sand and gravel, or by loamy or clayey sediments. The top of a stream terrace is transversely level and slopes parallel to the axial stream, whereas a fan remnant[32] slopes at about a right angle to the axial stream and is composed of crudely sorted, poorly stratified alluvium.

In broad basins not deeply dissected by their axial stream, and particularly near the head of a basin, *alluvial flats* may extend far back to either side of the shallow channel of the axial stream. The alluvial flats may have *fan skirts* along their margins (Fig. 14-1) or merge with the fan piedmont if there is no fan skirt. Where the axial stream has been incised into a former bolson floor, or

[32]The term *terrace* should be restricted to use for identification of *stream terraces*, *beach terraces*, and *lake-plain terraces*, even though fan remnants are loosely called terraces in the vernacular. For naming landforms of intermontane basins, only former *axial-stream* floodplains are called stream terraces. All other floodplains are called inset fans and their remnants are fan remnants.

alluvial flat, nearly level topped *basin-floor remnants*[33] may stand above *inset fans* that are tributary to the axial stream (Figure 14-II). If gullys have dissected a fan skirt that once was the margin of the basin floor, the area will now consist of *fan remnants* and be part of the fan piedmont.

Incision of the axial streams in narrow basins soon destroys any alluvial flat and radiates onto the fan piedmont. Where such dissection is deep, fan remnants stand as bluffs along the axial drainageway (Fig. 13). *Inset fans* debouching from the dissected fan piedmonts commonly form narrow *fan skirts* or individual *fanlettes* that grade to the floodplain of the axial stream. The fan skirt or fanlettes may be slightly scarped by stream meanders.

Lacustrine landforms, dunes, and sand sheets do not occur in most semi-bolsons, unless they were once inundated by an arm of a deep pluvial lake. Dust fall and infiltration and shallow loess mantles are probably as common as in bolsons.

LANDFORMS OF MAJOR DESERT STREAM VALLEYS

Where major Pleistocene rivers cut valleys through intermontane basins filled with alluvium, characteristic landform sequences occur (Ruhe, 1962, 1964, 1967, Hawley, 1980). The *valley floor* is comprised of *stream channels* and a *floodplain*. Stream meanders may have scarped *stream terraces, valley-border fans* (i.e., individual or coalescent alluvial fans debouching from *arroyo valleys*[34]) and *valley-border pediments* to form an *inner-valley scarp*. Along other reaches, the valley-border fans and pediments may grade to the floodplain.

Stepped sequences of erosional remnants of early-Holocene and Pleistocene fans and pediments, each graded to successively lower main-stream floodplain elevations, commonly form the *valley walls*, or valley slopes, of major desert stream valleys, rather than smooth, undissected slopes. These remnants may include significant areas of relict surfaces, or they may have been reduced to *valley-border ballenas*. Since late-Pleistocene and Holocene erosion has been mainly responsible for creating such ballenas, their slopes are apt to have only Entisols or weakly expressed pedogenic soils, whereas truncated Pleistocene soils are sometimes still prominent on their crests.

The upper, or *outer-valley rim* may be scarped and prominent if it is cut into a relict basin surface containing a soil with a petrocalcic horizon that acts as a cliff-former. The rim is apt to be most clearly defined and continuous along reaches cut into a high old basin floor from which few drainageways enter the valley. Where the valley rim impinges on a piedmont slope, it is apt to be deeply serrated by arroyo valleys extending far onto the piedmont slope and even into mountain valleys. Stepped valley-border surfaces may be represented within the arroyo valleys by inset-fan and pediment remnants.

LANDFORMS OF HILLS AND MOUNTAINS

Hill and *mountain* are utilitarian names for landscape features that impede travel and agriculture. Hills[35] rise less than 1000 feet above surrounding lowlands, whereas mountains are higher. Both have smaller summit areas than mesas or plateaus. They also have bedrock cores mostly mantled with variable depths of regolith in which pedogenic soils commonly occur. Barren bedrock exposures are only locally extensive. Moderately to extremely steep slopes are common, but the regolith and soils on these slopes are not necessarily, or even commonly, shallow. Other than these gross generalities, little can be said about component landforms or their relations to soils because there have been no studies of the geomorphology and soils of hills or mountains[36] comparable to those for intermontane basins (e.g., Ruhe, 1964, 1967; Gile and

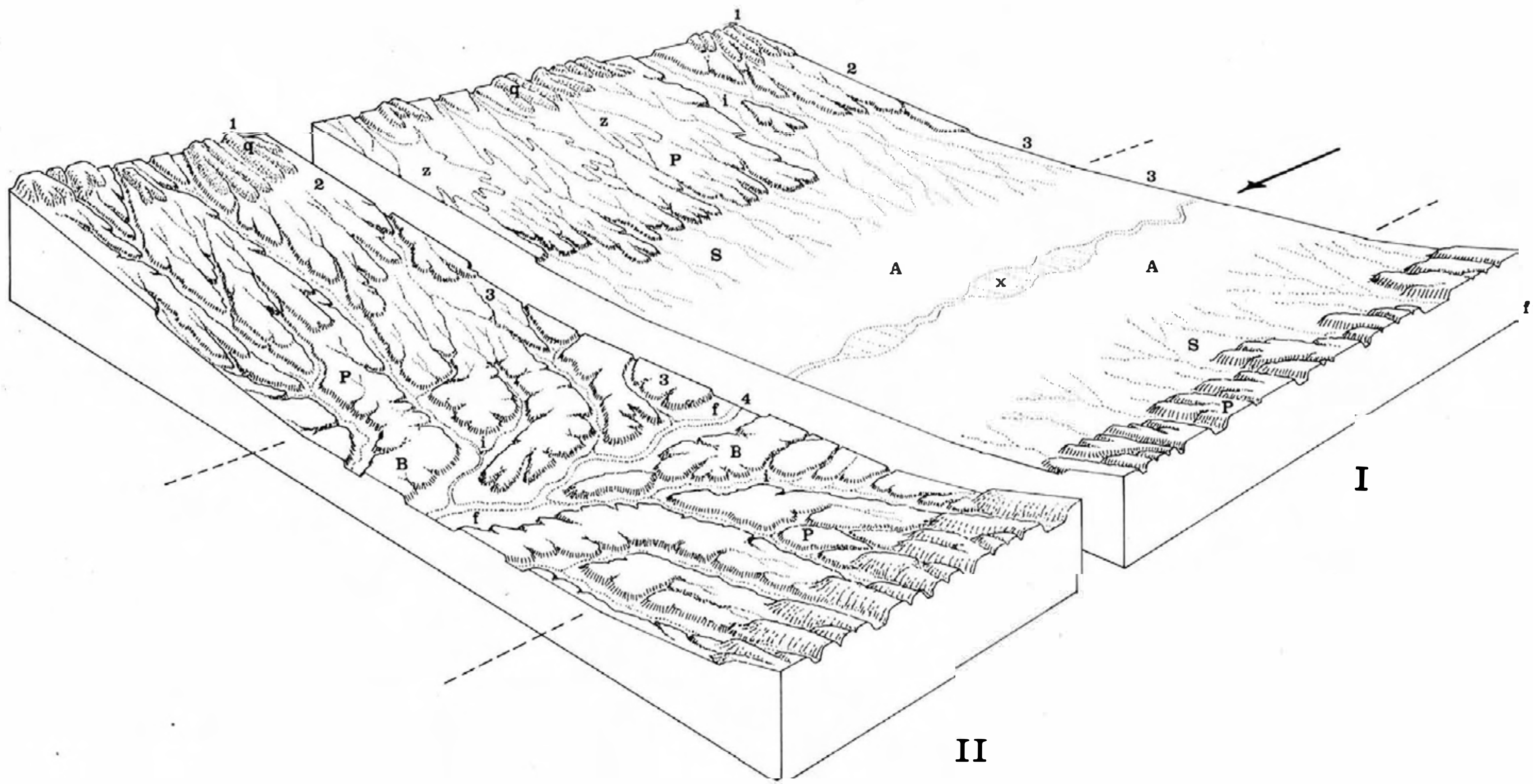
[33]The term *basin-floor remnant* is intended to be general and to include remnants of playas, lake plains, alluvial plains, and alluvial flats since these can be distinguished only difficultly by their sediments.

[34]This term for small valleys tributary to major desert stream valleys was coined in New Mexico, hence the provincialism *arroyo* in arroyo valley (cf., Hawley, 1980). It can serve to distinguish the drainageways of the ephemeral streams proliferating away from major desert stream valleys for the entire Basin and Range Province. The term, arroyo valley, denotes a type of drainage system, more than a landform. Its valley may contain an inset fan, fan remnants, pediment remnants, etc.

[35]The term *hill* should not be used for landforms of the piedmont slope or basin floor of intermontane basins, even though ballenas and other remnants have been loosely called foothills or hills in the vernacular.

[36]The numerous geological studies of mountain landforms are biased toward glacial features and almost all lack even rudimentary soils information. Geographic studies mostly use landforms too gross to relate to soils. Some morphogenetic landform identifications for soil survey have been done for the northern Rocky Mountains (U.S.D.A., 1976), but they are not widely applicable to the Basin and Range Province.

Figure 14. Diagrams of segments of a semi-bolson floor and its adjacent piedmont slopes, one before incision of the axial stream into the alluviated floor *(I)*, and the other after incision and proliferation of the new cycle of dissection onto the piedmont slopes *(II)*. The arrow shows direction of axial-stream flow, and the broken lines indicate the breadth of the basin floor. Landforms of segment *I* are: the *alluvial flat (A)*, *axial-stream-channel* and *floodplain-playa* segments *(x)*, *fan skirts (S)*, *fan piedmonts (P)*, *inset fans (i)* between fan remnants, *fan aprons (z)* overplaced on the relict fan piedmont surface, and *ballenas (q)*. This first segment of the basin shows evidence of three ages of land surfaces: *(1)* ballenas that are ridgeline remnants of some very old fan surface, now obliterated; *(2)* the fan-piedmont remnants, whose summits are the same age, or possibly younger than the ballena slopes; and *(3)* the inset fans and fan skirt grading to the alluvial flat, and the probably coeval fan aprons. The second basin segment *(II)* has yet younger surfaces *(4)* comprising an *axial-stream floodplain (f)* and tributary *inset fans (i)* between *basin-floor remnants (B)*. The fan skirt of basin segment *I* has been converted to a part of the fan piedmont of basin segment *II* upon dissection into fan remnants and aggradation of yet younger inset fans.



Grossman, 1979). Predicting where soils should occur on hills and mountains must be done by local, empirical correlations. This is unfortunate. However, the general theories and terms of *erosional slope formation* can be used to guide soil mapping and help name physiographic positions.

Hills, possibly excepting the larger ones, are small enough landscape features that they can be conceived of as single "major landforms" comprised of fairly simple erosional slopes on which the soil pattern is related to *slope components*. Mountains are such huge features that they comprise many different morphogenetic landscape features at the scales of the major and component landforms described for intermontane basins. Their sheer size allows factors of slope, aspect, and differential bedrock erodibility to manifest themselves in significant size areas. Zones of resistant bedrock may act as local baselevels for erosion behind which major or component landforms rise toward the mountain crests as steps, or as small erosional-valley systems graded to progressively higher nickpoints (cf., Wahrhaftig, 1965). However, many of these unnamed major and component landforms also can be described in terms of erosional slope components that have been shown to be related to ages of land surfaces and to soil patterns in many parts of the world.

A Model for Erosional Slopes

Erosional slopes cut in uniformly resistant material have remarkably similar forms and evolution patterns. Resistant strata only alter the form in understandable ways or direct the advance of erosion along certain routes. Generally speaking, the form of slope is independent of the size of the landform. The sides of a rill may have the same slope components and form as an entire hillslope or mountain slope, although the larger slopes are commonly mosaics of many smaller erosional slopes that display the similar form when viewed from a distance.

Figure 15 shows *profiles* of ideal examples of erosional slopes such as occur during the progressive reduction of a flattish upland surface by backwearing during a single erosion cycle. The upland surface is called a *summit* if it is broad and gently sloping enough that it is prominently distinguished from the steeper sideslopes. Where the top of a ridgeline remnant, or hill, or mountain is narrow and drops away immediately onto the sideslopes, it should be called a *crest*. The convex upper portion of the sideslope is the *shoulder*. It may be sharply angular if the summit is immediately underlain by a resistant stratum. Also, it may be narrowly or broadly rounded. The *straight* middle portion of the slope—which may be absent, if relief is low or the landform is very old—*and* the *prominently concave* lower portion *together* form the *backslope*. The *relatively gently sloping, slightly concave* slope leading away from the steeper backslope is the *footslope*, or *pediment*. At some indeterminant distance away from the backslope, the footslope may be called a *toeslope* to draw attention to an accumulation of sediment (eroded from the backslope and carried across the footslope) that is thicker than what is found on the footslope. The footslope—or the toeslope, if one is distinguished—extends on down to a lateral channel along which sediment eroded from the backslope is eventually discharged in "open systems". In "closed systems", where the footslope or toeslope ends in a drainage basin, the eroded sediment merely accumulates in the basin, gradually overriding the footslope as the basin fills (Ruhe, 1975).

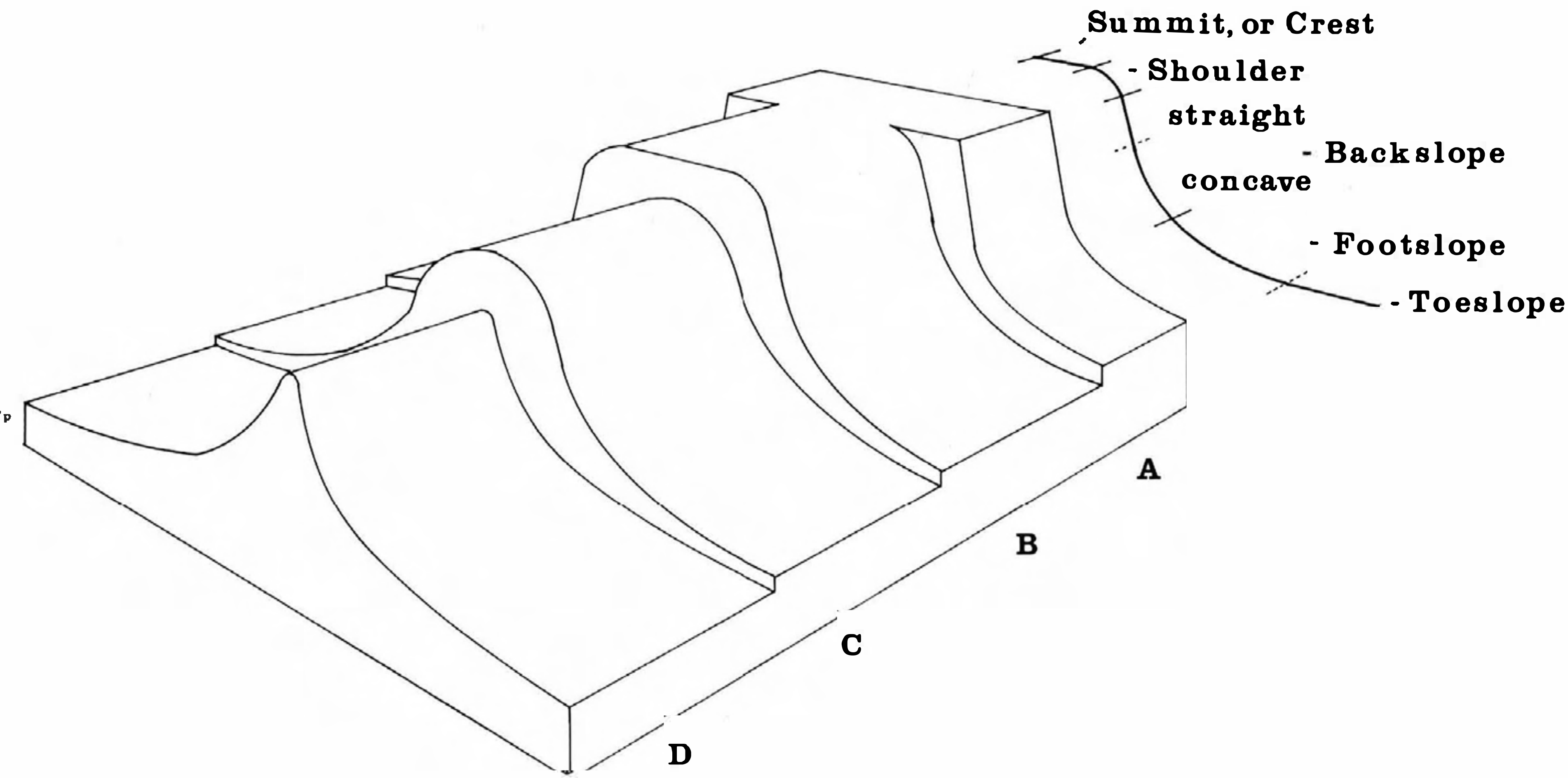
This pattern of *erosional-slope components* is the morphological reflection of a process that operates to produce low ridges, hills, and mountains all over the world under both humid and arid climates (Ruhe, 1975, pp. 125-148). Figure 16 diagrammatically shows the critical factor in the process: the *retreat*, or *backwearing*, of the shoulder and backslope after they have been initially formed by a cycle of gullying, or as a fault scarp. Large landforms and entire erosional landscapes are shaped by repeated cycles of gullying and backslope retreat from numerous drainageways (Fig. 11; cf. Ruhe, 1975, p. 135). The sequences of slope angles, shapes, and slope components—as an upland mass is reduced by this process of slope retreat—have been the subjects of longstanding geomorphic argument, as indeed has been the very existence of slope retreat in comparison to overall downwearing (cf., Young, 1972).

The summit, shoulder, backslope, footslope, and toeslope components each have been referred to by other genetic names associated with one or the other geomorphic theory. To save confusion, these alternative terms are best avoided, but two are so common in geomorphic literature and so useful that they need mention. The lower, prominently concave portion of the backslope has been called the *debris slope*. Coarse colluvium is apt to accumulate on it until disintegrated by weathering or until residual gravel and cobbles are buried under sediment as a thin layer that has the appearance of a *stone line* in vertical exposures. (But "stone lines" seldom contain many stone size rock fragments!)

Traditionally, the footslope has been called a *pediment* where it is cut into bedrock. There is no traditional equivalent term for footslopes cut into unconsolidated sediments (the most common case), although the term *parapediment* has been used informally. Furthermore, pediments were once thought to form only under arid climates, but are now known to occur widely in semiarid and humid climates. Ruhe (1975, p. 134) has amplified the definition of *pediment* to cover all situations where this morphogenetic form is found as an erosional-slope component: ". . . *a pediment should be considered an erosion surface that lies at the foot of a receded slope, with underlying rocks or sediments that also underlie the upland, which is barren or mantled with sediment, and which normally has a concave upward profile*. . . ." Ruhe's inclusive use of the term *pediment* is recommended.

The pediment is a surface of transport, just sloping enough that sediment eroded from the shoulder and backslope can be carried slowly to a drainageway channel or basin. The sediment is apt to form a layer, called *pedisediment*, that is about the depth of scour-and-fill of the rills that move it. The actual pediment erosion surface is at the base of the pedisediment and is apt to be marked by a stone line of gravel and cobbles that originally accumulated on the debris slope but could not be carried across the pediment. Stone lines are not formed if resistant gravel and cobbles are not produced during slope retreat. Or, they can not be distinguished if the upland and underlying materials are both very gravelly and cob-

Figure 15. A schematic diagram of the slope components of various forms of erosional slopes. A broad, flattish top is called a *summit* and is an older surface than the erosional sideslopes. Narrow tops of joined shoulders are called *crests*. Their surface is the same age as the sideslopes. The *backslope* may have a straight upper part or be concave throughout its length. The *footslope* is the gentle, slightly-concave slope at the base of the backslope. A *toeslope* portion of the footslope may be differentiated by a thicker accumulation of pedisediment than on the upper footslope. The different forms suggest both the variability seen in nature and the genetic sequence resulting from shoulder rounding and backslope retreat: *(A)* a hillform—or, by extrapolation, a mountainform—with a broad, flattish summit and sharply angular shoulders, such as would occur if the summit were directly underlain by a resistant stratum or soil horizon. *(B)* A hillform with a broad summit, rounded shoulders, and a short, straight, upper backslope. *(C)* A hillform with broadly rounded shoulders that have met and formed a crest lower than the original summit. The backslope has no straight-slope portion. *(D)* A hillform where retreated backslopes have lowered and sharpened the crest. The downward inset of each successive segment of the diagram allows the profiles to be shown and suggests progressive lowering of the divide once the shoulders have joined. However, the footslope would *not* be down-worn as the backslope retreated (cf., Fig. 16) and the crest position could be offset by unequal backslope retreat.



bly, as in fan alluvium. Pedisediment is apt to accumulate to depths greater than scour-and-fill toward the lower end of the pediment. This part of the slope is called the toeslope, or on a piedmont slope may be part of an inset fan.

The pediments and pediment remnants that can be associated with soil patterns in intermontane basins seems to be the result of recession of backslopes high enough that their retreat destroys entire pedogenic soils. The relict soils of fan and pediment-remnant summits show little evidence of truncation by erosion. But across the shoulder of an erosional slope cut into such a summit, the relict soil is commonly found to be progressively truncated and then absent from the backslope, footslope, and toeslope. But not all, if indeed most backslopes have been eroded recently enough to destroy any pedogenic soil that might have formed on them. Numerous examples are seen where the entire backslope is mantled with pedogenic soils that may be even equally as well developed as those of the summit. This latter situation is evidence that the sideslope has been stable almost as long as the summit. In yet other cases, short reaches of the backslope have been eroded recently and have no pedogenic soil, whereas contiguous reaches have a pedogenic soil. Land surface *stability* (soil formation) and *erosion* (soil destruction) are *periodic events both in time and space* (Butler, 1959), even on backslopes, which are the slope component most susceptible to erosion.

The erosional slopes of bedrock hills and mountains are such large features and so commonly have crests rather than summits, that patterns of differential soil development on crests and sideslopes are seldom seen that as clearly illustrate shoulder and backslope retreat at the expense of summits as those of fan-remnants. Yet, some hillslopes have strongly developed pedogenic soils, whereas others have only Entisols, or are bare rock. These situations may be contiguous. Localized hillslope erosion commonly radiates upward and outward by gullying and rilling initiating at the head of a drainageway cut into the footslope. The eroded area usually has an obovate shape. Such localized areas of hillslope erosion have been metaphorically called *erosion balloons* (Mock, 1972). Sediment from an erosion balloon exits through the incised footslope drainageway, rather than spreading across the footslope. Thus a relict soil of a footslope or pediment remnant is *bypassed* and protected from either rapid erosion or burial even though the associated backslope has been rejuvenated. Such localized erosion on backslopes explains patterns of different age soils along what seems to be a uniform age hillslope. Such situations also show that hillslope erosion by rilling, gullying, creep, or slides is periodic both in time and space and is apt to remove entire pedogenic soils. Indeed, hillslope retreat may depend on long periods of stability so that moisture held in the soil can produce "rock waste" by deep weathering, and thus a layer thick enough to be liable to rapid gully erosion, perhaps during transitions to drier climatic regimes.

There is evidence for *sheet erosion* and *shallow creep* as processes that shallowly and slowly truncate the pedogenic soils of hillslopes. These processes may have been overemphasized due to awareness of man's sometimes catastrophic land use. Their roles in determining hillslope soil patterns are not as clear as those of the rilling and gullying that create erosion balloons, but they do seem related to the patterns of erosional slope components described earlier.

Geometric Slope Shapes

Hillslope components also can be described by their *gradient* (as percent slope or degrees inclination), by their *length*, and by their *width*. Their geometric shape may be *convex, straight (linear),* or *concave* in both *profile* and *planimetrically*, giving nine possible combinations (cf., Ruhe, 1975, p. 100). But, gradient and shape commonly change with distance downslope and along the slope of erosional landforms. Slope length and width change with landform size without any necessary relation to landform genesis or soil patterns. Geometric slope properties are most useful for describing polypedons[4]. The morphogenetic slope components are more useful for describing physiographic positions and soil patterns.

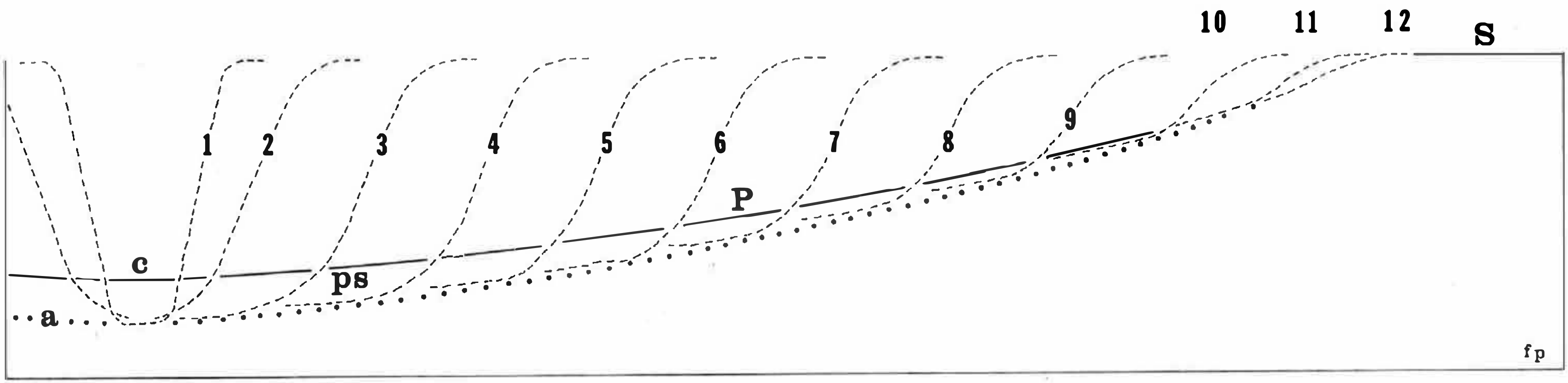
Patterns of Slope Components

Actual hillslopes—and by extrapolation, mountain slopes—are oversimplified by the slope components shown in Figure 15. First, in much hilly and mountainous terrain, most of the landscape consists of shoulders and backslopes. Summit, footslope, and toeslope areas are minimal. Many backslopes drop directly into drainageway channels. Secondly, hillslopes that are wide and straight along the contour, such as suggested by Figure 15, are rare. Rather, hill and mountain sides are apt to be cut into numerous short noses or longer spurs by sideslope drainageways and short side valleys. These in turn may be cut by yet smaller drainageways and rills. Thus, in plan view, the sideslopes of a hill or mountain ordinarily form a wavy, crenulated, or digitate pattern.

For any two adjacent spurs, each has three major planimetric shapes of slopes. On the *noseslope* at the ends of the spurs, the shoulder and backslope components are planimetrically convex. Water flowing down a noseslope spreads radially and would not be expected to be as apt to concentrate in large rills or gullies as on planimetrically straight or concave slopes. Sediment from the noseslope might be expected to be dispersed around its arcuate footslope. The spur *sideslopes* are nearly linear in plan view. Water flowing down these sideslopes may or may not collect into major rills or gullies. Sediment may collect on the debris slope to form thicker deposits than on the upper backslope or shoulder. As the sideslopes of a spur backwear, and the shoulders from either side meet, the crest of the spur is downcut and the hillmass reduced. A *headslope* occurs at the head of the drainageway or small valley between two spurs. The headslope is doubly concave: both in plan view and in profile. Runoff concentrates on the debris slope and may form prominent rills and gullies. Bifurcation of the interspur drainageway rising from the bottom of the headslope is common. Colluvium and sediment are very apt to accumulate on the debris slope and thick deposits and thick soils are apt to form in it. As a headslope backwears, it divides and reduces the main hillmass until eventually the shoulders from opposing headslopes meet, lower the hill crest, and form a col, or saddle.

According to Young (1972), the erosional processes on shoulders are still an enigma, although long ago soil creep

Figure 16. A schematic, cross section diagram of pediment formation by the retreat, or backwearing, of an erosional slope (positions *1* through *12*) into a relatively old summit surface *(s)*. Material eroded from the shoulder and backslope washes across the footslope, or *pediment (P)*, to a channel *(c)* as a layer of *pedisediment (ps)* that commonly is thicker toward the toeslope. The pedisediment lies on top of the actual erosion surface *(a)* which may be marked by a *stoneline*, as indicated by the line of dots.



was proposed to be the dominant process, as compared with rilling and surface wash on the backslope. (But rills are seen extending all the way to the crest.) Nonetheless, hill shoulders may be extensive components for local correlation with soil patterns, and their shape, or radius of curvature is one of the major elements that lends visual distinctiveness to hills and mountains that are recognized as looking "different".

Describing Soil Patterns on Hills and Mountains

Physiographic positions of individual soils on hilly or mountainous terrain are most specifically described by slope components. These terms cover such a wide range of landform sizes that it is helpful to add the adjective *hill* or *mountain* for a sense of landscape. *Mountain summit area*, for example, implies a larger, more highly elevated area than *hill summit*, and a *mountain footslope* implies a longer slope than a *hill footslope*. For some audiences, such loosely defined terms as *hillslopes* or *mountain slopes* are more acceptable than multiple or individual listings of *shoulders, backslopes*, or *footslopes*, but the general terms may not differentiate the positions of individual soils in a soil assocation. Similarly, *hill* or *mountain sideslope* may be used to merely imply the backslope position, but since they include the shoulder and footslope positions, such loose usage can confuse the positions of individual soils. As a result, one should *spellout* the physiographic positions of individual soils, or components of soil associations, if the purpose is to *add information on individual soil locations* to the necessarily somewhat vague locations provided by the delineations of soil associations on small scale, reconnaissance soil maps.

If one's purpose is to only suggest landscape positions for a nontechnical audience, or to indicate the positions of entire delineations of a soil association, then the loose terms, such as *hillslopes*, are appropriate. To describe the landscapes of very broad soil associations, such as those of general soil maps, single terms are ineffective. One should go to narrative descriptions using any selection of terms that work.

Hilly or mountainous landscapes can be quite different in various areas. Distinctively similar hills or mountains—which occur locally in groups and have characteristic soil associations—look alike because they have similar elevations and sizes and shapes of slope components. Sharp crests formed by angular, or narrow, tightly rounded shoulders create smooth or jagged skylines, both of which contrast with those of hills or mountains having flattish summits, or wide summits formed by joined, very broadly rounded shoulders. Hills with narrow ridgeline crests and long, straight backslopes dropping directly into intervening narrow drainageways have an overall serrate aspect that suggests geologically recent and intense dissection. Other hills have broadly rounded crests that merge, without any intervening straight backslope, into broadly flaring, concave backslopes and footslopes. Such hills seem to stand apart from each other and their open valleys invite a traveler's entrance. Their slopes also suggest great age if they are cut in hard bedrock. They are also apt to be soil-mantled, albeit thinly.

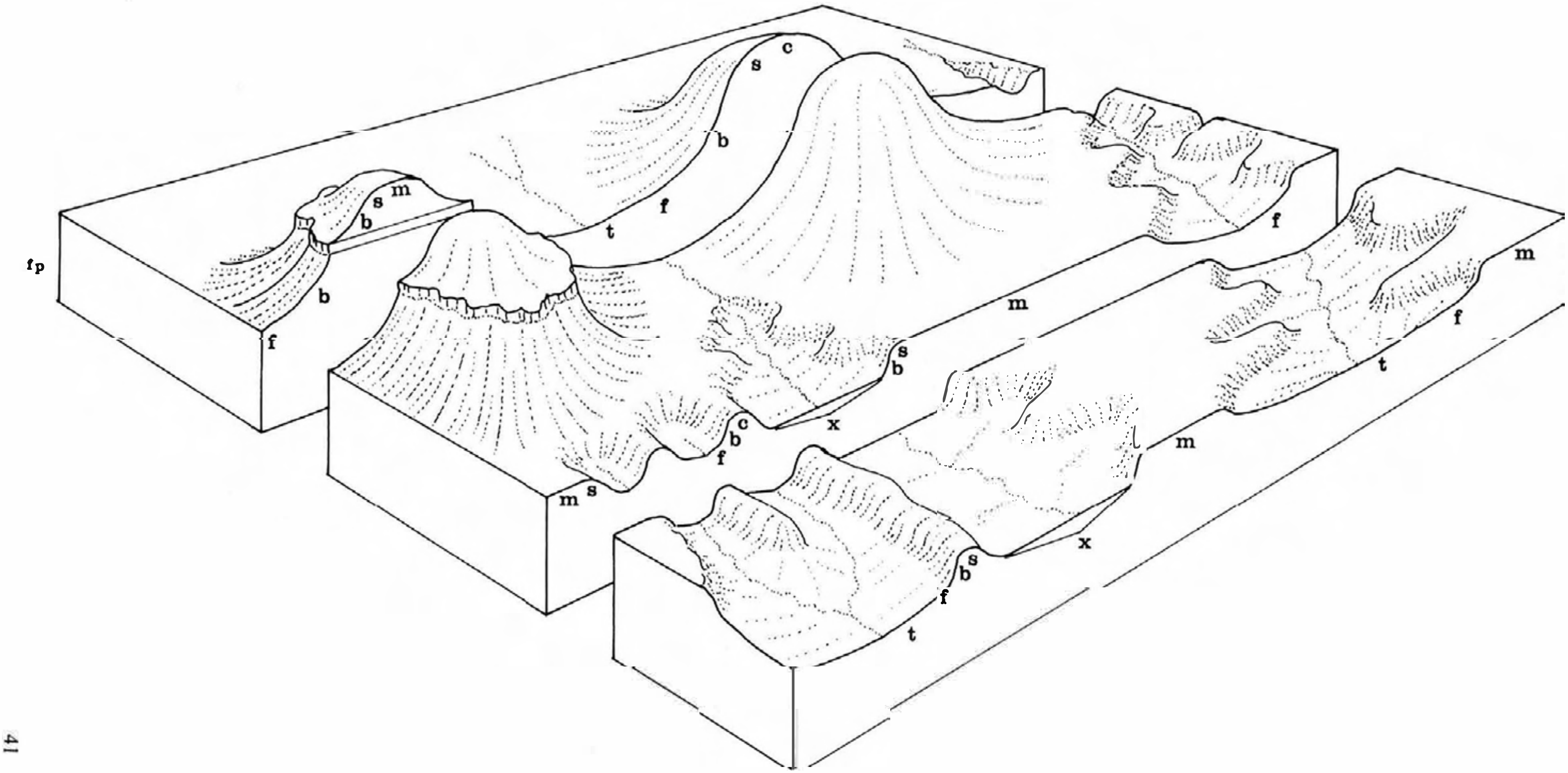
Asymmetric hills and hills with cliffed slopes suggest differentially resistant bedrock. At detailed scale, common, jagged, barren bedrock outcrops suggest recent stripping and sparse soil whereas smoothly curving slopes suggest a continuous soil mantle. In general, the shallowest soils are apt to occur on doubly- or singly-convex slopes. Deeper soils may be expected on doubly- or singly-concave slopes. Figure 17 suggests how slope components may be used to describe hilly, mountainous, and dissected landscapes and the physiographic positions of individual soils.

LANDFORMS FOR SOIL MAP UNIT DESIGN

Landform analysis is probably most useful for designing and describing the soil association map units of Order 3 and 4 soil surveys (Appendix I, Table 1). Not uncommonly, the major landforms of intermontane basins occur in zones that are potential soil associations, or the zones can be broken into a few subdivisions with consistent soil patterns. The reader of one of these soil surveys may be satisfied with mere percentage soil composition and a loose description of where the soil associations occur. The major physiographic part or major landform names are useful for telling where entire soil associations occur. For example, one might occur on the *piedmont slope*, or somewhat more specifically, on *both dissected alluvial fans and dissected fan piedmonts*. But, if the reader is going to use the soil map to apply management practices in the field, he will need to be able to find the component soils. This demands identification of the physiographic position of each soil by component landform, landform elements, or slope component, or in reference to one of these features if soil boundaries do not accord with landform boundaries. For example, three soils of an association may occur on *inset fans, fan-remnant sideslopes*, and *fan-remnant summits;* an entire delineation of this association would be on a *dissected fan piedmont*. As another example, two soils may occur in a complex with no topographic clues to their boundaries. They might be described as occurring on *slightly dissected fan piedmonts with soil A under big sagebrush and soil B under low sagebrush*.

The map units of Order 3 and 4 soil surveys necessarily have considerable *inclusions* (cf., Appendix I, Table 2). Since relatively small map scales are used, the included soils may cover surprisingly large and prominent areas when encountered in the field (Appendix II). The user's confidence in the soil map is greatly increased if inclusions are described for each map unit, and if the physio-

Figure 17. Hypothetical erosional hillforms and dissection landforms illustrating how slope component names can be used to describe the physiographic positions of soils. The slope components are: *summit (m), crest (c), shoulder (s), backslope (b), footslope (f),* and *toeslope (t).* A drainageway *(x)* that has been so deeply alluviated that the former footslope and toeslope are buried now contains an inset fan. The hill at the upper left has its backslope interrupted by a *cliff* formed by a resistant stratum. The other particularly broadly and smoothly rounded hill is called a *ballon* (A.G.I., 1972). The ridges at the lower left are *ballenas* if cut in fan alluvium. The summit above the erosional slopes cut by the gully system at the lower right would be relict fan surfaces if underlain by fan alluvium, or in this depicted situation, they could be remnants of a pediment left by retreat of the hillslopes. Note the curving, or cuspate, planimetric pattern of the footslopes (i.e., pediments) of the drainageway bottoms.



graphic position of each is given so the user can anticipate where they will be seen.

The map units of the detailed soil maps for Order 2 soil surveys are mostly soil consociations and the map scales are relatively large. Since the location of only one kind or phase of soil is identified by each consociation delineation, and since the base map ordinarily provides excellent field control, physiographic position is not so critical for the user. Yet landform recognition is equally useful during soil mapping. Most trained readers will want an idea of landscape position when they are studying the map unit descriptions. The general soil map in an Order 2 soil survey report is like an Order 4 soil map. It is most useful if its soil associations accord with major landscape units and if the positions of the dominant soils are given by landform.

Order 5 soil survey maps are necessarily drawn using large landscape units as map units. Their descriptions should be in general landform terms commensurate with the generality of the soil map units, e.g., *rolling hills*, or *piedmont slopes*. If the positions of the dominant soils are described by more specific landform terms, the utility of the map is increased.

The extremely detailed maps of Order 1 soil surveys deal with such small areas that physiographic position is not needed for location. However, it may suggest environmental hazards such as flooding or frost hazard.

GEOMORPHIC SURFACES

Landform identification aids soil mapping because it separates some, if not all soils of different ages. A *geomorphic surface* is another landscape abstraction that is used to specifically identify soil age. Identification of geomorphic surfaces involves landform analysis, but landforms and geomorphic surfaces are not synonymous. A geomorphic surface may comprise a single landform, several landforms, or *parts* of yet others. A geomorphic surface is a part or several parts of the land surface *that has been formed during a particular time period.* A soil that underlies a geomorphic surface has an age dating from somewhere within the time period during which the surface was formed, i.e., the soil dates from the time the surface was stabilized—neither being eroded or aggraded—and that date ordinarily can be described only as within the time period and relative to the age of some other geomorphic surface. This is sufficient for soil mapping and most soil genesis studies.

The concept of geomorphic surfaces and their relations to landforms is best defined if it is *operationally defined*[37], i.e., if the things one *does* to map, date, and describe geomorphic surfaces are used to define the concept. Three interacting sets of operations are involved: (1) locating the surface spacially, or mapping it; (2) dating this land area by stratigraphic evidence; and (3) recognition (a mental operation) that the "surface" is not only a plane—in the sense of a geometric abstraction that has length, width, and elevation coordinates, since it curves—but that identificaion of the surface also involves the sediments, soils, or rocks that form the particular land surface in its different parts (cf., Ruhe, 1969, pp. 5-6).

A geomorphic surface is only an abstraction, as all map identifications are, of a portion of some very real landscape. During the operations of mapping a geomorphic surface, one not only discovers facts about a landscape and tests mapping criteria, but also creates the mental items that are used to establish age by stratigraphic relations and to correlate landforms, soils, and geomorphic surfaces. The mapping of the geomorphic surface, or surfaces, of an alluvial fan located along a mountain front can serve as an example of how one uses landform analysis and then other landscape features to identify geomorphic surfaces in the field, i.e., to operationally define them.

In this example, the alluvial fan is first seen and then mapped as a discreet landform. That is, one would delineate the part of the landscape which is found to: (1) have a fan-like, or semiconical shape, (2) have its apex at the mouth of a mountain valley, and (3) be in a broad lowland downslope from the source of (4) the stratified alluvium, and perhaps debris flow deposits, from which its gross topographic form has been constructed—whether or not it has later been dissected. These are the operational criteria that define the alluvial fan landform. During mapping the fan of this example, one may find that the fan's surface is (1) so smooth that the ephemeral washes currently distributing sediment across it have no topographic barriers to periodic lateral migration, and that (2) the entire fan is mantled with raw, entisolic alluvium that contains no significant pedogenic horizons.

One could then conclude that this fan surface is of a single age and is recent. Actually, portions of the surface should be somewhat different ages because the ephemeral washes that build an alluvial fan (and hence its surface) by spewing fresh alluvium back and forth take some years to work across the entire fan. Therefore, its recent age is actually a period of time, a period short enough and sufficiently recent that no pedogenic soil has formed. Thus, a part of the land surface has been delineated that has been formed during a time period defined by the surficial alluvial mantle and its lack of pedogenic alteration. It is a *geomorphic surface* which, in this example, was formed by a single process.

Again taking this example of a recent alluvial fan, one could try to map the eroded valley slopes that provided the fan alluvium and may be able to logically assign an age to them. Suppose that during the period the entisolic veneer was spread across the alluvial fan, contemporane-

[37]Bridgeman (1927) gives a short, readable discussion of how scientific knowledge is gained which is as applicable to soil science and geology as to his subject of physics. His *operational definition* is one of the principles on which the *Soil Taxonomy* (USDA, 1975) was built (Cline, 1963). The most useful discussion of geomorphic surfaces for soil scientists is by Daniels *et al* (1971).

ous gullying of portions of the valley slopes resulted in destruction of a preexisting soil—a not unknown event. The boundary between the remnantal pedogenic soils and the freshly exposed parent material on the valley slopes would enclose the area from which the fan alluvium was derived. The eroded valley slopes and the fan surface could then be said to be the same age, where age is the period of time needed to strip the valley slopes deeply enough to destroy a soil, and to contemporaneously deposit a veneer of fan alluvium thick enough to contain an Entisol. Now, one land form (the fan) and part of another (the eroded portion of the valley slopes) that are the *same age*, though formed by different processes, would have been mapped. These comprise a *single* geomorphic surface. One would predict a similar degree of soil formation (i.e., Entisols) as far as this geomorphic surface could be mapped onto other landforms by similar operations.

The example illustrates how a geomorphic surface might be identified in one particular situation. It also introduces the difficult question of what *surface* means in the context of soil studies. To pursue the question, additional examples of the operations used to identify and differentiate geomorphic surfaces are needed.

Let the alluvial fan example be altered by saying that there are erosional fan remnants that stand several feet above the recent fan surface still crossed by active washes (i.e., above inset fans). The fan-remnant summits must be older than the active fan surface, and can be used to define a second, older geomorphic surface (cf., Fig. 5). The remnant summits must be older because they stand in a position where the washes could not have deposited raw alluvium during the period the recent fan surface was being constructed. Surfaces in such a position are said to be *bypassed* by active streams. Note that before such remnants can be securely identified as being bypassed, and therefore as having relatively old summit surfaces, they must have a very real topographic relief. A few millimeters or inches higher isn't enough to map consistently. Such bypassed remnants may be destroyed by erosion, but in the interim they just set and weather. Pedogenic soils[38] are commonly found on bypassed fan-remnant summits and none, or more weakly differentiated ones on the sideslopes and younger inset fan surface.

As a third example, many fan piedmonts have old surfaces preserved between fan aprons or where, by some accident they have not been veneered with raw alluvium for a long time (cf., Fig. 10). Such nonburied remnants and relict fan surfaces also are old geomorphic surfaces. These surfaces are identified by several alternative or combined criteria. In hot deserts, old surfaces commonly have a pebble pavement darkened by desert varnish, whereas a recent alluvial veneer is apt to have light colored, unvarnished surficial pebbles (cf., Denny, 1965, p. 9, 11). To use this criterion, one assumes desert varnish forms only very slowly; such a single criterion is a weak and crude differentia for surface age. A more significant observation would be finding a pedogenic soil within the remnant and no pedogenic soil, or a less prominently differentiated one in contiguous, presumably younger alluvium. This sort of age identification extrapolates previously determined correlations between pedogenic alteration and surface age, and the argument is substantial. If the pedogenic soil of the nonburied remnant can be traced under and hence shown to be *buried* by a relatively unaltered, stratigraphically-younger alluvial veneer, or fan apron, the argument for a significantly older geomorphic surface is conclusive. Note that real, substantial thicknesses of material are needed to demonstrate either the presence or absence of pedogenic soils in both the remnant and the fan apron.

The operations for identification of mappable geomorphic surfaces significant to soil studies involve real thicknesses of soil material, *thicknesses great enough that they contain or could contain a pedogenic soil*[38]. It is meaningless, in Bridgeman's (1927) sense of the word, to speak of a geomorphic surface as if it were a geometric plane of zero thickness, or a sand grain's thickness, or a few inches thickness because that is not enough to allow the operations of identification.

One implication of this operational requirement is that when mapping a geomorphic surface by visual extrapolation from one erosional remnant across a drainageway to another flattish remnant, or by the sweep of the eye across a smooth and apparently continuous surface such as a fan skirt, it must be with the presumption that there has not been enough truncation or sediment deposition to destroy or to bury a pedogenic soil within the areas that look to be one geomorphic surface. A second implication is that where a geomorphic surface appears to extend from, say, an alluvial deposit with an identifiable surficial layer onto a barren rock pediment, or onto an apparently very shallowly sheet eroded area, the continuation of the geomorphic surface must remain moot.

Geomorphic surfaces are useful for soil mapping inasmuch as there are two basic kinds of surfaces: stable and active. A *stable geomorphic surface* may be defined as

[38]In the most general sense, *soil* is material in which plants grow, or could be grown. A *geologic soil* may be defined as weathered and loosened rock, residuum, or sediment without any pedogenic horizons. A *pedogenic soil* has at least one *pedogenic horizon* that is (1) an *altered* layer, that (2) *parallels* the land surface, and that (3) is *somewhere discordant* with the macroscopic structure or microscopic fabric of its assumed geologic parent material. The *alteration* distinguishes the layer from others above or below it, and lends it an identifying character. Alteration may be made by *accumulations*, such as through additions of humus or illuvial clay, by *losses*, such as through the solution of limestone or through clay eluviation, or by *changes*, such as through the mixing of finely-stratified sediment, or formation of soil structure, or gleying, or the release of iron to form brown oxides. *Parallelism* demonstrates that the alteration is the effect of processes acting from the land surface to various depths with different effects at different depths. Most of these processes involve the percolation of meteoric water. For example, humus accumulates where roots grow most vigorously. Illuvial clay accumulates below a surface horizon that acts as a source or transport zone, and calcium carbonate accumulates at the common depth of wetting in soils with xeric, ustic, and aridic moisture regimes. *Discordance* demonstrates that the alteration happened after the horizon's parent material was emplaced or formed by geologic processes, i.e., by preceding events. Development of soil structure and mixing that disrupt fine stratifications of alluvium or dune sand, or that disrupt the relict rock structure of saprolite are discordances with geologic parent material structure. Cementation of stratified sand and gravel by calcium carbonate or opal is another macroscopic discordance. Illuvial clay coatings and bridges in alluvial sand are examples of microscopic discordance to geologic fabric because sand is not deposited from running water with such coatings or bridges (Peterson, 1980). If these three criteria cannot be demonstrated for a putative pedogenic horizon, then it should be considered a *geologic horizon*. Some very deep or very thick horizons, or horizons with very diffuse boundaries which have features suggestive of pedogenesis may have to be called geologic horizons, therefore, because examination is physically impractical.

one where there is a pedogenic soil in the surficial material that forms the surface. A geomorphic surface may be *active* by reason of recent or ongoing erosion or deposition that has destroyed or buried a preexisting pedogenic soil. By this definition, erosion that merely truncates a pedogenic soil may change the taxonomic identity of the soil, but the surface is still "stable". One may speak of "partial instability", if partial truncation can be demonstrated. Burial creates an active surface if the mantle is thicker than an arbitrary 50 cm (20 inches), or is between 30 and 50 cm thick, and the thickness is at least half of that of the diganostic horizons preserved in the buried pedogenic soil (cf., USDA, 1975, p. 2). Lesser accreations may be called "partial instability," but are difficult to map and in time will be converted to pedogenic horizons probably indistinguishable from those of the buried soil. The definitions adopted here may seem unnecessarily demanding, but they reflect the operational realities for identifying geomorphic surfaces significant for soil studies.

In summary, geomorphic surfaces are *mappable land surface areas that were formed during a defined time period by deposition or erosion of at least a thickness of material sufficient to accommodate a pedogenic soil*[38]. They are the basic tool for determining soil age, but probably are more difficult to map than soils. Landforms are more easily recognized and frequently can be used to informally identify local geomorphic surfaces, at least in part (cf., Fig. 8). A given landform may be comprised of one or several geomorphic surfaces, and a single geomorphic surface may extend across several landforms. Geomorphic surfaces may be defined for geological purposes with time spans broad enough to include several ages of stable surfaces and pedogenic soils, but for soil studies, they are best defined narrowly, if possible. Landforms are a basis for predicting soil occurrence, describing the physiographic positions of soils, and may indicate relative age. The geomorphic surface is the device whereby landforms can be used to establish relative ages of different soils and further help predict where they might occur.

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F.F.P.
Reno, Nevada
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APPENDIX I

KINDS OF SOIL SURVEYS AND SOIL SURVEY TERMS

TABLE 1

CRITERIA FOR IDENTIFYING KINDS OF SOIL SURVEYS[1]

Kinds of Soil Survey	Kinds of Map Units	Kinds of Taxonomic Units	Field Procedures[2]	Appropriate Scales for Field Mapping and Published Maps	Minimum Size Delineation[3]
Order 1	Mainly soil consociations and some complexes	Phases of soil series	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Air photo interpretation[5] used to aid boundary delineation.	>1:10,000[4]	<1.0 acre
Order 2	Soil consociations, associations, and complexes	Phases of soil series	The soils in each delineation are identified by transecting or traversing. Soil boundaries are plotted by observation and air photo interpretation and verified at closely spaced intervals.	1:10,000 to 1:30,000	1.0 acre to 9.0 acres
Order 3	Soil associations and some soil consociations and complexes	Phases of soil series and soil families	The soils in each delineation are identified by transecting, traversing and some observations. Boundaries are plotted by observation and air photo interpretation and verified by some observation.	1:30,000 to 1:80,000	9.0 acres 64 acres
Order 4	Soil associations with some soil consociations	Phases of soil families and soil subgroups	The soils of delineations representative of each map unit are identified and their patterns and composition determined by transecting. Subsequent delineations are mapped by some traversing, by some observation, and by air photo interpretation verified by occasional observations. Boundaries are plotted by air photo interpretations.	1:60,000 to 1:125,000	36 acres to 156 acres
Order 5	Soil associations	Phases of soil subgroups, great groups, suborders and orders	The soils, their patterns, and their compositions for each map unit are identified through mapping selected areas (15 to 25 sq miles) with Order 1 or 2 surveys, or alternatively, by transecting. Subsequently, mapping is by widely spaced observations, or by air photo interpretation with occasional verification by observation or traversing.	1:125,000 to 1:1,000,000 (publication scales)	156 acres to 10,000 acres

[1]Soil surveys of all Orders require maintenance of a soil handbook (legend, map unit descriptions, taxonomic unit descriptions, field notes, interpretations) and review by correlation procedures of the National Cooperative Soil Survey. Work plans for many survey areas list more than one order; the part to which each is applicable is delineated on a small scale map of the survey area. These criteria are after the report of *ad hoc* Committee 7, *Kinds of Soil Surveys,* Proceedings National Soil Survey Conference, Jan. 1975, Orlando, Florida, Soil Conservation Service, and the report of Committee 1, *Identifying Order 3 and 4 Soil Surveys,* Western Regional Work Planning Conference for Soil Survey, National Cooperative Soil Survey, Feb., 1980, San Diego, California. *The criteria and definitions of this Appendix are proposed but not yet official policy of the National Cooperative Soil Survey.*

[2]Field procedure terms are used with meanings defined in Table 2 of this Appendix.

[3]This *minimum size delineation* is the land area represented by the about minimum size area *on a map sheet*—at a given scale—within which a symbol can be printed (a ¼-x¼-inch square or roughly circular delineation of 1/16 square inch area). Such small delineations can be shown legibly only when isolated within much larger delineations. An exact map of intermingled polypedons which would show as minimum size delineations would be illegible; either the scale would have to be considerably enlarged, or soil complexes or associations shown instead of soil consociations. Smaller than minimum size delineations can be used with arrowed in symbols, or *spot symbols* can be used to locate isolated, very small, highly significant land areas.

[4]Order 1 soil surveys are made for purposes that require appraisal of the soil resources of areas as small as experimental plots and building sites. Mapping scale could conceivably be as large as 1:1.

[5]*Air photo interpretation* is meant to include interpretation of any remotely sensed data available.

TABLE 2

DEFINITIONS OF TERMS USED TO DEFINE KINDS OF SOIL SURVEYS

1. **Soil Survey:** A soil survey is a soil map and accompanying report which is based on field investigations and usually supported by air photo interpretation.

2. **Soil Maps:** Soil maps show the geographic distribution of different kinds of soil and their map units are named and defined by their component soils. Soil maps are made for many different purposes.

   Some objectives require refined distinctions among kinds of soil that occupy small homogeneous soil areas. Other uses require broad perspective of the soils of large distinctive areas. Three kinds of soil maps are distinguished on the basis of the procedures that produced them.

   2A. **Soil Survey Map:** Generated by field investigations with varying amounts of supporting information from photo interpretations.

   2B. **Generalized Soil Map:** Produced by combining contiguous delineated areas of preexisting soil maps that were made by field procedures to make larger delineations on a new map.

   2C. **Schematic Soil Map:** This kind of soil map is made by predicting kinds of soils and the areas they occupy from existing information without the benefit of preexisting soil survey maps or more than very limited field investigations.

3. **Transect:** (1) The field procedure of crossing delineations or landscape units along selected lines to determine the pattern of polypedons with respect to landforms, geologic formations or other observable features. Thus, visible or simply determinable features are related to soils, and soil occurrence can be predicted locally from these features.

   Transects require explicit documentation including: (1) a symbol locating the transect on and keying the documentation to a field sheet (e.g., "T-73"); (b) a planimetric sketch of the location of the transect within the delineation showing variations from a straight line, etc.; (c) a cross-section diagram of the component soils, associated vegetation, landforms, geology, etc.; (d) a pedon description of each component soil; (e) a statement of the landscape factor related to each soil boundary; and (f) the percentage soil component composition based on the entire transect length. This document validates the composition of soil map units (particularly soil associations) and explicitly shows the mapping clues by which additional delineations may be identified. Air photo interpretation is used during transecting.

   (2) Identifying pedons at regularly spaced intervals (i.e., gridding).

   Also, (3) a procedure of crossing delineations on selected or random lines, and identifying pedons at predetermined points for subsequent formal or informal statistical evaluation to establish the composition and variability of a delineation or mapping unit.

4. **Traverse:** Validation of the predicted boundaries or composition of a delineation by entering it or crossing it and identifying pedons at selected or random positions.

   A traverse requires that the significant horizons of each soil component in a delineation be examined physically by shovel or auger. For Order 3 and 4 surveys, the location of the examination should be shown by a symbol within the delineation drawn on the field sheet, and keyed to field notes if notes are made. If all component soils of a delineation are not examined or the examination site is not located by a symbol the mapping operation shall be considered an "observation." Air photo interpretation is used during traversing.

5. **Observation:** Visual checking of landscape features, exposed geological formations, or chance exposures of pedons from within or without a delineation to project boundaries and composition from previously determined relations; air photos may be used as guides. This is a less intensive operation than traversing.

   Identification of component soils by observation uses air photo interpretation, but requires an *on-ground view* close enough that individual shrubs, stones, and chance exposures of soil horizons can be seen clearly, i.e., closer than a few hundred yards. Air photo interpretation, or views from aircraft are not "observations." Examples of observations: seeing fragments of a petrocalcic, or a ditchbank exposure of an argillic horizon from a pickup window. A two-foot high scarp that is known to separate soils, but is not visible on stereo air photos. Cobbles of limestone on a hillside that are a clue for a particular soil. Indicator plants or changes in shrub height or density that is related to soil change. The sensation of softer or firmer soil when walking across an area, and noting it is related to soil color and apparent texture. Salt efflorescences.

6. **Air Photo Interpretation:** Plotting boundaries and estimating composition of delineations based on air photo features that have been related to soils and landscape features. As the term is used here, air photo interpretation includes applicable remote sensing.

   Airphoto interpretation is a strictly intellectual, second hand conclusion based on *previous* correlation of landscape features and photo patterns to soils. In comparison, an "observation" is a concrete, novel experience where many more landscape features are apparent and their significance can be tested, than is possible with air photos, particualrly at scales appropriate for Order 3 and 4 mapping.

7. **Sampling:** Taking physical samples from pedons or selected horizons for later laboratory or field analyses. The soil material is called a soil specimen.

8. **Identification:** (1) The systematic determination of the properties and features of a pedon (or pedons of a polypedon), including laboratory analyses where needed, and subsequent keying through an established soil classification system to find the class(es) within which the pedon (or polypedon) fits or in the absence of such a class(es), determination of status as a soil variant or soil taxadjunct. This operation concerns naming of individual things from an existing classification.

   Also, (2) the immediate perception (i.e., the *gestalt*) on viewing or brief examination of the class name of a pedon or polypedon.

9. **Classification:** The conceptual grouping and separation of similar and dissimilar polypedons subsequent to examination of a large enough number of these individuals to provide a more-or-less valid sample of a population of real soils in some geographic area. Although concepts from existing classifications unavoidably guide examination and grouping, stress is placed on the properties of a real population of individuals, whereas during identification, stress is on relating an individual to the classes of an existing classification. During soil mapping, classification-type thinking is used to set up relatively few new soil series, or families, or phases, whereas identification-type thinking is used routinely for naming numerous soil areas.

10. **Correlation:** The field and office procedures of review by which the accuracy and appropriateness of taxonomic unit identification, map unit design, mapping legends, field notes, pedon descriptions, and other soil survey operations are maintained.

11. **Delineation:** A selected and differentiated portion of a landscape that contains a unique composition and pattern of soils and is identified by a boundary on a map. The boundary of a delineation can be placed at the boundary of a polypedon identified by use of soil series-level differentia, or at the boundary of a polypedon or contiguous polypedons identified by use of soil family (or higher)-level differentia, or at the boundary of a landscape unit containing a describable pattern of soils or land types described at any categorical level.

12. **Map Unit:** A map unit is a conceptual group of many delineations—but occasionally only one delineation—which represent very similar landscape units comprised of the same kind of soil or miscellaneous land type, or *two or more* kinds of soils or miscellaneous land types. The map unit definition, or description, names and identifies the soils or land types of the delineations by taxonomic units. Inclusions also should be described if they have been identified. For soil associations and complexes, proportion and landscape pattern of components should be described.

13. **Taxonomic Unit:** A taxonomic unit is the complete identification of a soil or miscellaneous land type component of a map unit, hence of delineations. Commonly a soil taxonomic unit consists of a class name from any categorical level of the Soil Taxonomy plus phase distinctions such as slope class.

14. **Soil Consociation:** A map unit in which only one identified soil component (plus allowable inclusions) occurs in each delineation. The term *consociation* is needed to identify map units of only one identified component. It is manufactured from the element *con* ("opposed to" or "negative") and the element *sociate* (from association, "to join," "to share," "companion") and means things which are single, *not* a companion of other things. The term has been used by plant ecologists to identify stands of single species as opposed to associations of several plant species.

15. **Soil Association:** Definition as given in Soil Conservation Service Soil Survey Memorandum 66.

    Alternative Unofficial Definition: A soil association is a map unit in which two or more named soil components occur in each delineation in described proportions and pattern and the component soils can be located in the field by landscape features. The named components are individually large enough to be delineated at a 1:20,000 scale.

16. **Soil Complex:** Definition as given in Soil Conservation Service Soil Survey Memorandum 66.

    Alternative Unofficial Definition: A soil complex is a map unit in which two or more named soil components or miscellaneous landtypes occur in each delineation, the boundaries of which cannot be mapped at 1:20,000 scale, *or* the boundaries of the component soils cannot be accurately plotted without closely spaced gridding since the soil boundaries cannot be correlated with visible landscape features.

APPENDIX II
GUIDE TO MAP SCALES AND MINIMUM-SIZE DELINEATIONS

Order of Soil Survey Map	Map Scale	Inches per Mile	Minimum Size Delineation[1]	
			acres	hectares
	1:500	126.7	0.0025	0.001
	1:2,000	31.7	0.040	0.016
ORDER 1	1:5,000	12.7	0.25	0.10
	1:7,920	8.0	0.62	0.25
	1:10,000	*6.34*	*1.00*	0.41
	1:15,840	4.00	2.5	1.0
ORDER 2	1:20,000	3.17	4.0	1.6
	1:24,000 (7.5′)	2.64	5.7	2.3
	1:30,000	*2.11*	*9.0*	*3.6*
	1:31,680	2.00	10.0	4.1
ORDER 3	*1:60,000*	*1.05*	*36*	*14.5*
	1:62,500 (15′)	1.01	39	15.8
ORDER 4	1:63,360	1.00	40	16.2
	1:80,000	*0.79*	*64*	*25.8*
	1:100,000	0.63	100	40
	1:125,000	*0.51*	*156*	*63*
	1:250,000	0.25	623	252
ORDER 5	1:500,000	0.127	2,500	1,000
	1:750,000	0.084	5,600	2,270
	1:1,000,000	*0.063*	*10,000*	*4,000*
Very	1:7,500,000	0.0084	560,000	227,000
Generalized	1:15,000,000	0.0042	2,240,000	907,000
Soil Maps	1:88,000,000	0.0007	77,000,000	31,200,000

[1]The *minimum size delineation* is taken as a ¼-x¼-inch square or circular area of 1/16 sq. in. area. Cartographically, this is about the smallest area in which a symbol can be printed readily. Smaller areas can be delineated and the symbol lined in from outside, but such very small delineations drastically reduce map legibility. Minimum size delineations must occur as *isolated* areas within much larger delineations for good map legibility. A map composed of largely minimum size delineations is illegible and impractical. Such a map can be reprinted at larger scale, or redrafted with adjacent delineations combined into larger delineations (i.e., more generalized map units such as soil complexes and soil associations) for improved legibility.

GLOSSARY

The terms in this glossary are defined only for the context of intermontane basins.

Aggradation—The building of a floodplain by sediment deposition; the filling of a depression or drainageway with sediment; the building of a fan by deposition of an alluvial mantle.

Alluvial—Pertaining to processes or materials associated with transportation or deposition by running water.

Alluvial fan—A semiconical, or fan-shaped, constructional, major landform that is built of more-or-less stratified alluvium, with or without debris flow deposits, that occurs on the upper margin of a piedmont slope, and that has its apex at a point source of alluvium debouching from a mountain valley into an intermontane basin. Also, a generic term for like forms in various other landscapes.

Alluvial flat—A nearly level, graded, alluvial surface between the piedmont slope and playa of a bolson or the axial-stream floodplain of a semi-bolson. This major landform may include both recent and relict components.

Alluvial plain—A major landform of some basin floors, comprised of the floodplain of a major Pleistocene stream that crossed the floor, or of a low gradient fan-delta built by such a stream. It is distinguished from an alluvial flat by its relatively well sorted and stratified alluvium.

Arroyo valley—A small valley tributary to a major desert stream valley.

Association—See *soil association* in Appendix I, Table 2.

Backslope—The slope component that is the steepest, straight then concave, or merely concave middle portion of an erosional slope.

Ballena—(pronounced *by-een-a*) A major landform comprising distinctively round topped ridgeline remnants of fan alluvium. The ridge's broadly rounded shoulders meet from either side to form a narrow crest and merge smoothly with the concave backslopes. In ideal examples, the slightly concave footslopes of adjacent ballenas merge to form a smoothly rounded drainageway.

Bar—(*Offshore* and *barrier bars*) A component landform comprised of elongate, commonly curving, low ridges of well sorted sand and gravel that stand above the general level of a bolson floor and were built by the wave action of a Pleistocene lake.

Basin—A loose abbreviation for *intermontane basin, bolson,* or *semi-bolson.* Also, an area of centripetal drainage or a structural depression.

Basin floor—A generic term for the nearly level, lowermost major physiographic part of intermontane basins, i.e., of both bolsons and semi-bolsons. The floor includes all of the alluvial, eolian, and erosional landforms below the piedmont slope.

Basin-floor remnant—A flattish topped, erosional remnant of any former landform of a basin floor that has been dissected following the incision of an axial stream.

Beach—A generic term for offshort bars, barrier bars, and beach terraces.

Beach plain—A major landform of bolson floors comprised of numerous, closely spaced offshore bars and intervening lagoons built by a receding Pleistocene lake.

Beach terrace—A component landform occurring on the lower piedmont slope that consists of a wave-cut scarp and a wave-built terrace of well sorted sand and gravel marking a still-stand of a Pleistocene lake.

Bolson—A specific identification for an internally drained intermontane basin.

Bolson floor—A specific identification for the floor of a bolson as compared with a semi-bolson floor.

Bypassed—The situation of a fan or pediment surface that once had sediment spread across it by ephemeral washes, but that is now protected from surficial stream erosion or alluviation because the drainageways crossing it are now incised.

Channel—The bed of a single or braided watercourse that commonly is barren of vegetation and is formed of modern alluvium. Channels may be enclosed by banks or splayed across and slightly mounded above a fan surface and include bars and dumps of cobbles and stones. Channels, excepting floodplain playas, are landform elements.

Component landforms—Commonly small landforms that *compose* part of the *area* of a major landform and were created by partial dissection of, or by alluvial or eolian accretion on that larger, major landform. Component landforms are about the smallest landforms that can be usefully conceived of as a single unit. Their morphological parts are landform elements, and the sideslope element may be subdivided into slope components.

Consociation—See *soil consociation* in Appendix I, Table 2.

Crest—The slope component that is the very narrow, commonly linear top of an erosional ridge, hill, mountain, etc., cf., summit.

Debris flow—The rapid mass movement of a dense, viscous mixture of rock fragments, fine earth, water, and entrapped air that almost always follows a heavy rain. A *mudflow* is a debris flow that has dominately sand size or smaller particles.

Delineation—See *delineation* in Appendix I, Table 2.

Desert stream valley—The valley of a perennial stream that is fed from mountain sources and is erosionally-cut through several desertic semi-bolsons.

Dissection—The partial erosional destruction of a land surface or landform by gully, arroyo, canyon, or valley cutting leaving flattish remnants, or ridges, or hills, or mountains separated by drainageways.

Erosion balloon—A metaphorical term for commonly obovately shaped, eroded sideslope areas that normally empty into an incised drainageway and are surrounded by noneroded sideslopes.

Fan—A generic term for constructional landforms that are built of more-or-less stratified alluvium and that occur on the piedmont slope, downslope from their source of alluvium.

Fan apron—A component landform comprised of a sheet-like mantle of relatively young alluvium covering part of an older fan piedmont (and occasionally alluvial fan) surface. It somewhere buries a pedogenic soil which can be traced to the edge of the fan apron where the soil emerges as the land surface, or relict soil. No buried soils should occur within a fan-apron mantle; rather, they separate mantles.

Fanlette—A very small, normally undissected alluvial fan, something less than a few tenths of a square mile in area that may occur below a gully, inset fan, or ravine in a variety of positions on the piedmont slope or within mountain valleys.

Fan collar—A component landform comprised of a thin, short, relatively young mantle of alluvium along the very upper margin of a major alluvial fan at a mountain front. The mantle somewhere buries a pedogenic soil that can be traced to the edge of the fan collar where it emerges as the land surface, or relict soil.

Fan-head trench—A relatively deep drainageway originating in a mountain valley and cut into the apex of, and commonly across an alluvial fan. It may empty into an interfan-valley drainageway, debouch onto the fan piedmont, or cross the fan piedmont.

Fan piedmont—The most extensive major landform of most piedmont slopes, formed by the lateral coalescence of mountain-front alluvial fans downslope into one generally smooth slope without the transverse undulations of the semi-conical alluvial fans and by accretion of fan aprons. Fan piedmonts commonly are complexes of many component landforms.

Fan skirt—A major landform comprised of laterally coalescing, small alluvial fans that issue from gullies cut into, or are extensions of inset fans of the fan piedmont and that merge along their toeslopes with the basin floor. Fan skirts are smooth or only slightly dissected and ordinarily do not comprise component landforms.

Fan remnant—A generic term for component landforms that are the remaining parts of various older fan landforms that either have been dissected (erosional fan remnants) or partially buried (nonburied fan remnants). Erosional fan remnants must have a flattish summit of relict fan surface; nonburied fan remnants are all relict fan surface. Fan remnants may be specifically identified as fan-piedmont remnants, inset-fan remnants, etc.

Fan-remnant sideslope—A landform element comprised of the relatively young erosional slope around the sides of an erosional fan remnant. It is composed of shoulder, backslope, and footslope slope components.

Floodplain—The transversely level floor of the axial-stream drainageway of a semi-bolson or of a major desert stream valley that is occasionally or regularly alluviated by the stream overflowing its channel during flood.

Floodplain playa—A component landform consisting of very low gradient, broad, barren, axial-stream channel segments in an intermontane basin. It floods broadly and shallowly and is veneered with barren fine textured sediments that crusts. Commonly, a floodplain playa is segmented by transverse, narrow bands of vegetation, and it may alternate with ordinary, narrow or braided channel segments.

Floor—A generic term for the nearly level, lower part of an intermontane basin (a bolson or semi-bolson) or a major desert stream valley.

Footslope—The relatively gently sloping, slightly concave slope component of an erosional slope that is at the base of the backslope component; *syn:* pediment.

Fluve—A linear depression, rill, gully, arroyo, canyon, valley, etc., of any size, along which flows at some time, a drainageway.

Geomorphic surface—A mappable area of the land surface formed during a defined time period by deposition or erosion (or both, in different parts) of at least a thickness of material sufficient to accommodate a pedogenic soil. Its age (i.e., period of formation) ordinarily is defined by relations to other geomorphic surfaces, or by the soils or sediments that form or underlie the surface.

Headslope—See *sideslope*.

Hill—A highland mass that rises less than 1,000 feet (300 meters) above its surrounding lowlands and has merely a crest or restricted summit area (relative to a mesa).

Inset fan—A special case of the floodplain of a commonly ephemeral stream that is confined between fan remnants, basin-floor remnants, ballenas, or closely opposed fan toeslopes. Its transversely-level cross seciton is evidence of alluviation of a fluve. It must be wide enough that raw channels cover only a fraction of this component landform's surface.

Interfan-valley drainageway—A drainageway or drainage system rising as onfan drainageways that combine to form a trunk drainageway down the axis of an interfan valley, i.e., down the topographic low between two adjacent mountain-front alluvial fans. Fanhead trenches may empty into interfan-valley drainageways. The latter may debouch onto or cross the fan piedmont.

Interfluve—The elevated area between two fluves (drainageways) that sheds water to them.

Intermontane basin—A generic term for wide structural depressions between mountain ranges that are partly filled with alluvium and are called "valleys" in the vernacular. Intermontane basins may be drained internally (bolsons) or externally (semi-bolson).

Intramontane basin—A relatively small structural depression within a mountain range that is partly filled with alluvium and commonly drains externally through a narrower mountain valley.

Lagoon—A metaphorical term for the ponding area behind a Pleistocene offshore or barrier bar (beaches) that collects fine textured sediments.

Landform—A three dimensional part of the land surface, formed of soil, sediment, or rock that is distinctive because of its shape, that is significant for land use or to landscape genesis, that repeats in various landscapes, and that also has a fairly consistent position relative to surrounding landforms.

Landform element—A morphological part of a component landform. Sideslope landform elements may be divided into slope components.

Lake plain—A major landform of some bolson floors that is built of the nearly level, fine textured, stratified, bottom sediments of a Pleistocene lake.

Lake-plain terrace—A somewhat elevated portion and component landform of a lake plain.

Major landform—A subdivision of the piedmont slope or basin floor major physiographic parts that reflects a major morphogenetic process operating through a long time, or that is the prominent result of a special erosional or depositional history. Many major landforms are dissected and their original area now is occupied by component landforms.

Major physiographic part—A geographically very large part of an intermontane basin characterized by its dominant slope and position (i.e., steeply sloping mountains that stand above less-sloping piedmont slopes, that in turn grade to nearly level basin floors, and that is comprised of major landforms.

Mountain—A highland mass that rises more than 1,000 feet (300 meters) above its surrounding lowlands and has merely a crest or restricted summit area (relative to a plateau).

Mountain-valley fan—A major landform created by alluvial filling of a mountain valley or intramontane basin by coalescent valley-sideslope fans whose toeslopes meet from either side of the valley along an axial drainageway. It is an extension of the upper piedmont slope into mountain valleys. Most mountain-valley fans have been dissected.

Noseslope—see *sideslope*.

On-fan drainageway—A drainageway or dendritic drainage system that rises on an alluvial fan, fan piedmont, or fan remnant and that may debouch on the fan piedmont or cross it.

Parna dune—An eolian dune built of sand size aggregates of clayey material that commonly occurs leeward of a playa.

Partial ballena—A spur, with a fully rounded crest, that is connected to an erosional fan remnant large enough that some relict fan surface is preserved on the remnant summit (cf., ballena).

Pediment—The footslope component of an erosional slope; geomorphologically ". . . an erosion surface that lies at the foot of a receded slope, with underlying rocks or sediments that also underlie the upland, which is barren or mantled with sediment, and which normally has a concave upward profile. . . ." (Ruhe, 1975).

Pedisediment—A layer of sediment, eroded from the shoulder and backslope of an erosional slope, that lies on and is, or was, being transported across a pediment (footslope).

Pedogenic soil—see footnote 38.

Physiographic position—The location of a soil or other landscape feature by reference to landforms.

Piedmont—A general slope rising to mountains.

Piedmont slope—A major physiographic part of an intermontane basin that comprises all of the constructional and erosional, major and component landforms from the basin floor to the mountain front and on into alluvium-filled mountain valleys.

Plain—A flat, undulating, or even rolling area, larger or smaller, that includes few prominent hills or valleys, that usually is at low elevation in reference to surrounding areas, and that may have considerable overall slope and local relief (A.G.I., 1972).

Playa—An ephemerally flooded, barren area on a basin floor that is veneered with fine textured sediment and acts as a temporary or the final sink for drainage water.

Provenance—For sediment, the source area or source bedrock or source sediments.

Relict—Old, remaining from previous times; in the present context, Pleistocene.

Remnant—A remaining part of some larger landform or of a land surface that has been dissected or partially buried.

Ridgeline remnant—A narrow ridge with a fully rounded crest that is accordant with the crests of similar nearby ridges. Together these accordant crests approximately mark the position of a preexisting land surface that has been destroyed by dissection.

Rock-pediment notch—A very narrow rock pediment, or footslope, along the base of a bedrock hill or mountain slope.

Sand dune—An eolian dune and landform element built of sand size mineral particles. Dunes commonly occur on the leeward side of a Pleistocene lake bed.

Semi-bolson—A specific identification for an externally-drained intermontane basin.

Semi-bolson floor—A specific identification for the floor of a semi-bolson as compared with a bolson floor.

Shoulder—The convex slope component at the top of an erosional sideslope.

Sideslope—The erosional slope around the sides of an erosional fan remnant, hill, ballena, mountain, etc., that is composed of shoulder, backslope, footslope, and perhaps toeslope components. Also, the planimetrically-linear portions of the slopes around a digitately-dissected fan remnant or hill, etc., as compared with the planimetrically-convex noseslope and concave headslope portions.

Slope component—A morphological element of an erosional slope and a morphological subsidivision of the sideslope landform element.

Stream terrace—A transversely level erosional remnant of a former axial stream or major desert stream floodplain that slopes in the same direction as the adjacent, incised stream, and is underlain by well sorted and stratified sand and gravel or by loamy or clayey sediments.

Summit—The flattish top of an erosional fan remnant, hill, mountain, etc. The term is used for both a landform element and a slope component.

Terrace—In the vernacular, any part of a general slope that stands above a short, steep scarp and has a flattish, nearly level or gently sloping summit. It may have another short scarp above the summit, *syn.* bench. These two terms should not be used for fan or basin-floor remnants.

Toeslope—The lowermost portion of the footslope component of an erosional slope. It is distinguished from the upper footslope by a greater accumulation of pedisediment. Also, the lowermost, most gently sloping portion of any slope.

Valley—An elongated depression cut by stream erosion and associated water erosion on its sideslopes (stream valley). Also used in the vernacular for intermontane and intramontane basins.