# AIRPHOTO PATTERNS OF SOILS

## OF THE

## WESTERN UNITED STATES

**As Applicable to Airport Engineering**

By

**Robert E. Frost and K. B. Woods**
**Purdue University**

Technical Development Report No. 85



U.S. DEPARTMENT OF COMMERCE
CIVIL AERONAUTICS ADMINISTRATION

U. S. DEPARTMENT OF COMMERCE
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CIVIL AERONAUTICS ADMINISTRATION
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# *Foreword*

This report describes one phase of an investigation conducted for the Airport Development Division, Technical Development, of the Civil Aeronautics Administration, by the Joint Highway Research Project, Engineering Experiment Station, Purdue University. It supplements an earlier publication "The Origin, Distribution, and Airphoto Identification of United States Soils," Civil Aeronautics Administration Technical Development Report No. 52, May 1946.

Even before Technical Development Report No. 52 was published, it became apparent that supplemental work would be desirable in order that information concerning airphoto analysis of soils of the Western United States be brought up to a standard comparable with that developed for the Eastern States. This report, dealing with the supplemental work performed, describes the following airphoto patterns: Glacial materials of North Dakota and Montana; aeolian soils primarily of the Columbia Plateau; sandstone and shale materials of Montana and Wyoming; igneous materials from many States in the Northwest, including considerable information on the basalts of the Columbia Plateau; Great Plains outwash materials; and soils of filled valleys including the Willamette and the Great Valley of California, plus some Basin and Range data.

Special mention is hereby made of the assistance of the following: D. S. Jenkins, formerly of the Airport Development Division, Civil Aeronautics Administration, for developing the plan of study which was followed; Prof. D. J. Belcher, formerly of Purdue University and now with Cornell University, who assisted in the collection of the field data in connection with one of the extensive trips made to several Northwestern States; and R. C. Mainfort who edited and prepared the manuscript for publication for the Airport Development Division of the Civil Aeronautics Administration.

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# *Introductory Note*

Viewing the region west of the Mississippi River, widespread and important glacial materials are to be found in North and South Dakota and in Montana. In this portion of the Great Plains the materials are characteristically silty; widespread glacial deposits, including lacustrine soils, prevail. Topographically the region is ideal for the construction of airports.

In contrast to the confinement of glacial materials to the northern tier of States, aeolian materials are widespread throughout the entire country. Wind-worked sands are particularly abundant in western Washington along the Columbia River, while the channelized scab lands of the Palouse region of Washington constitute one of the important silt regions of the United States. Both wind-blown sands and silts are prevalent in the Great Plains region, particularly in Kansas, Nebraska, and Colorado.

The soft sandstones and shales of several of the States west of the Mississippi River include many materials deposited during so-called Tertiary times. These rocks are poorly consolidated and have undergone severe and prolonged erosion. The importance of a thin gravel mantle in modifying the erosional development of the sandstones and shales of Montana and Wyoming should not be overlooked. The airphoto pattern of these materials is in striking contrast to the sandstones and shale patterns of the rock of the Pennsylvanian Period outcropping in such States as Pennsylvania and West Virginia.

Various types of volcanic materials are distributed throughout most of the States of Western United States. In Montana and Wyoming may be found uplifts of considerable importance locally, all of which have their distinctive airphoto pattern. Many granites are to be found as well as upturned sedimentary strata which have been eroded into ridges or "hogbacks." The Columbia Plateau, a large region covering portions of Washington, Oregon, northern California, Nevada, and Idaho, is the outstanding basalt region of the country. Deposits of volcanic ash and pumice, which in some instances are important airport and highway materials, are extensive in many of these States.

Valley-fill materials and Great Plains outwash characterize most of the level areas of all the Western States. Important areas such as the Willamette Valley and the Great Valley of California are primarily structural basins filled with alluvial sediments. The level sections of the Basin and Range Province of Nevada and Utah are primarily filled valleys which contain some lacustrine sediments. Finally, the outwash materials of the Great Plains, particularly of Nebraska, Colorado, Kansas, New Mexico, and Texas, are unique in their method of deposition. These materials, in turn, produce equally outstanding airphoto soil patterns.

The technique for use of airphotos in the fields of airport and highway engineering is fully described in Chapter XIII of Technical Development Report No. 52. This report, consequently, is confined to a discussion and analysis of the geological aspects of the airphoto technique.

# Chapter I.—GLACIAL LAKEBEDS AND ASSOCIATED DEPOSITS

One of the important glacial soil areas, from the standpoint of airport sites, contains the class of soils commonly referred to as lacustrine. The widespread occurrence and size of old lakebed regions, together with their related soils and level topography, direct attention to airport location, design, and construction in these areas.

The following discussion covers the distribution of glacial lakebeds and their accompanying airphoto patterns. It supplements the following sections of Technical Development Report No. 52: Chapter II, Notes on Geology and Pedology, pages 5 to 19; Chapter V, Glacial Materials, pages 41 to 51; Chapter VIII, The Principles of Airphoto Interpretation, pages 76 to 86; and particularly Chapter XI, Airphoto Analysis of Glacial Materials, pages 87 to 97

## Distribution of Glacial Lakebeds

Many lakebeds are of sufficient size and importance to have been given names and many have had a direct influence on the agriculture and regional development in their respective locations. Some of the more important of these lakebeds are Agassiz, Souris, Dakota, Minnesota, Patoka, Chicago, and Maumee. (See the engineering soils map accompanying Technical Development Report No. 52 for location of lacustrine areas of glacial origin.) The largest is Agassiz which extends from southern North Dakota and Minnesota through Manitoba where it drains into Hudson Bay through the Nelson River. This is known as the Red River Valley of the North. Some of the principal cities in this great grain-producing area are Fargo, Grand Forks, and Winnipeg.

Glacial Lake Souris is in North Dakota and Manitoba and is part of the Souris River Valley. The Lake Chicago region is an extension of Lake Michigan and occurs as a narrow band around the southern end of the present lake. Chicago, Hammond, Gary, and part of Michigan City are located on the shores and lakebed of this ancient lake. Lake Maumee, similar to Lake Chicago, is a westward extension of Lake Erie and occurs in Indiana and Ohio, with the city of Fort Wayne being located in the western tip of the old lake. Lake Dakota is a long narrow area lying entirely in South Dakota and is part of the James River Valley in which the cities of Aberdeen and Huron are located.

Throughout the area once covered by Wisconsin glaciers are numerous small lakebed areas, many of which still remain as fresh-water lakes. However, those that have been drained either by natural or artificial means are rich in deposits of muck and peat, and frequently are underlain either by gravel or marl. Extensive muck and peat areas are found in Michigan, Wisconsin, Minnesota, and in the northern parts of Ohio, Illinois, and Indiana.

Equally important are the many broad, flat, elevated flood plains of the major streams that border the southern limits of glaciation. Southern Indiana contains a network of such lakebeds in some of the stream valleys tributary to the Ohio River.

## Origin

Glacial lakebeds are generally of two types: those lying within the boundaries of glaciation developed by ponded waters; and those located outside the glacial boundaries created by streams that were dammed by glacial debris. Those within the glaciated region occupy depressions in morainic areas, till plains, outwash channels that were blocked and ponded, and large preglacial basins or drainage ways.

Lakebeds in morainic areas or in depressions of till plains consist of deposits of silts, silty clays, and clays. The material composing the lakebed soils represents sediments brought to the lake by erosive and transporting processes. In general, the texture of lacustrine sediments bears direct relation to the size of the lake, the source of the material, and the sorting action of moving water. Large lakes, such as Agassiz, contain vast areas of deep silts and clays. Most glacial lakebeds have a deep organic topsoil formed subsequent to recession. Many of the larger lakes, such as Agassiz, Chicago, and

Maumee, contain terraces and beach ridges which were formed during differentials in lake elevation. Sand dunes, such as those in northern Indiana, represent the reworking of the beach sands by the wind.

Peat and muck have been produced from the large accumulation of vegetative matter that resulted from blocked outwash channels. Because glacial outwash channels are usually associated with large volumes of swift-moving melt water, the soil textures are relatively coarse. These two phenomena, occurring at different periods following glaciation, account for the close association of muck with gravel.

The glacial lakebeds outside of the limits of glaciation are found in valleys which drained the glacial areas and owe their origin to the blocking of the stream valleys by glacial debris. This resulted in the flooding of low areas adjacent to the streams as well as the flooding of other isolated depressions. When the dammed-up streams receded, the flood plains which had become lakebeds were left as elevated terraces. Many of the inland water courses were isolated and became true inland lakes. Texturally, the soils are similar to those of other lakebed areas with plastic clays predominating in the broad areas where current action was slight. In this respect the broad elevated flood plains of the Ohio River Valley, lower Wabash River Valley, lower White River Valley, and the Patoka Valley are all in the glacial-lakebed class.

Figures 1 to 16 are airphoto and ground-photo illustrations showing variations in the soil patterns of lakebeds and some associated lakebed deposits such as dunes, terraces, and beach ridges.

## General Aspects of the Airphoto Soil Pattern

One of the first impressions gained by inspecting aerial photographs of lakebeds is the apparent absence of pattern markings. This is understandable, especially in the case of large lakebed areas, because of the absence of relief and the uniformity of land use. The following discussion is concerned with the more important elements of the lakebed soil pattern which can be correlated with soil textures and engineering problems.

### Land Form

A flat plain is the result of the method of deposition of lake-laid sediments. The local relief at any one area, however, may not always be flat since ridges and channels often occur in lakebed areas. Erosion subsequent to the recession of the water may or may not affect the pattern. These features, constructive and destructive, which control the land form, are always evident in the airphoto pattern. For example, in lakebeds used for agricultural purposes, flat topography is always accompanied by a rectangular field pattern. Channel scars are evidenced by their generally parallel sweeps that are somewhat directional in trend. This is accompanied by a change in land use or in vegetative cover.

### Soil Color

The soil color tone of the airphoto of lakebeds depends on several items including groundwater table, actual color of the soil (black, brown, gray, etc.), vegetative cover, soil texture, topographic position, and presence or absence of organic material. High groundwater conditions will cause a soil to photograph dark; therefore, such items as spoil banks of ditches, low knolls, or a vegetative change are invaluable aids in identifying textures. Furthermore, dark-colored soils photograph dark (muck, peat, organic clays, and organic silts) unless a close-growing leafy crop obliterates the natural soil color in local areas. Deep silt soils occurring in a well-drained position will photograph light in color. In separating organic clays from silts, the gully shapes must be studied closely because both types of soils appear as dark areas in photographs.

### Erosion and Drainage Pattern

The location of gullies with respect to main and tributary drainage channels is important in analyzing the soil textures of lakebeds. Comparison of the drainage pattern of Lake Souris with that of Agassiz shows the importance of this feature. The Souris River in western North Dakota has cut a deep channel in the lakebed and is a degrading stream, while the Red River (Lake Agassiz) is building a natural levee in the lakebed and has not cut a deep channel.

Many lakebed gullies are insignificant because they are shallow and broad and often are difficult to identify and trace in the fields; gullies are of great importance, however, in the interpretation of lake-laid soils from airphotos since the gully shapes are a clue to the texture of soils. This is especially important in lakebed regions since the plastic lakebed soils develop a gully shape rarely duplicated in dissimilar textured soils. The slopes of the gully in lakebed soil are the same, regardless of depth of the gully. This can be illustrated by comparing the gullies of Lake Souris (North Dakota) with those of Lake Chicago (Indiana) or with those of southern Indiana. The importance of erosional features can be observed in the study of the coulees of Lake Souris. The main river valley lies over 100 feet below the lakebed level and valley-wall dissection has produced a rugged local topographic condition.

### Vegetation

The airphoto pattern of lakebeds reflects clearly the climatic influence. In the Souris region, for example, the lakebed proper contains no trees. Wooded areas are confined to the alluvial soils of the river valley many feet below the lake floor. Detailed analysis of the photos shows the coulees are lined with dense shrubs. This is in contrast to the heavy timber growth in the southern Indiana lakebeds (fig. 13).

### General Discussion

Glacial lakebeds, because of their mode of origin, high ground-water and highly plastic soils, require special study when considered for airfield location. Site selection in large areas such as the Agassiz region provides an example. The best locations for airports, strictly from the standpoint of soil characteristics, would be on the broad granular or semigranular beaches that fringe the lake. Construction on porous materials reduces maintenance costs as well as the outlay for the original construction.

## Chapter II.—AEOLIAN SOILS—WIND-BLOWN SAND AND LOESS

Aeolian soils constitute one of the outstanding engineering soil-groups of the country. They are widespread and are marked by the uniformity of their physical characteristics and, consequently, the similarity of engineering construction and design problems which they present. The more general aspects (origin and location) of aeolian soils and their related airphoto patterns have been discussed in Technical Development Report No. 52 in the following chapters: Chapter II, Notes on Geology and Pedology, pages 5 to 19· Chapter IV, Loessial Soils, pages 34 to 40; Chapter VIII, Principles of Airphoto Interpretation, pages 76 to 86; and particularly Chapter X, Airphoto Analysis of Aeolian Soils.

The description of the origin, distribution, engineering problems, and airphoto interpretation of loessial soils presented in chapters IV and X of the above-mentioned publication leaves little to be added as a supplementary discussion of the more general aspects of this soil pattern. In areas where silt soils are relatively shallow, however, the resulting airphoto patterns may contain pattern elements of both the silt as well as those of the underlying material. In such areas, successful interpretation depends on intensive study of even the smallest details. This is particularly true in areas of shallow silt on Illinoian Glacial Drift because the drift material itself is also high in silt content.

### The Wind-Blown Sand Pattern

The aeolian pattern rarely is duplicated among the airphoto soil patterns of other soil groups. Wind-blown sand, particularly, always presents its own characteristic pattern which cannot be attributed to any other soil group. The pattern exhibited is always consistent, whether dunes are crescent-shaped piles of sand bordering the shores of lakes and oceans (Indiana Dunes Park, the Gulf coast, Florida coast, etc.), cross-bedded dunes (sand-hill country of Nebraska), gypsum sands (New Mexico White Sands National Monument), black volcanic sand (near Moses Lake, Wash.), or combinations of several types.

The action of wind always leaves its telltale imprint which shows flow, streamlining, and direction. Wind-blown sand, because of its porous nature and continuous shifting, rarely develops a soil profile. The characteristic shape of a dune is usually sufficient to identify it as a deposit consisting of sand. Gullies are practically nonexistent in sand dunes; hence the airphoto pattern may be considered as having only three elements: the characteristic dune shape, the color (light gray to white), and sparse vegetative cover. Figures 17 to 22 are a series of airphotos and a ground view that illustrate a few of the airphoto elements of the sand-dune pattern.

## The General Loess Pattern

The loess pattern and its many variations, in contrast with the wind-blown sand pattern, are often complex and contain a wide variety of photo elements which must be closely observed for successful interpretation. Extreme care must be exercised in studying minute details.

Patterns reflecting deep loess lend themselves more readily to interpretation than those of areas of shallow loess on unrelated materials. The deep loess pattern has several dominating elements that enable the interpreter to classify the material, while shallow deposits (5 feet or less) have no standard elements—only variations of elements characteristic of each material. Due to its complexities, the loess pattern is difficult to describe. One difficulty lies in the climatic-vegetative influence. In arid or semiarid regions such minute details as "cat steps," gully shapes, or pinnacles show clearly on photographs because of the absence of a screening vegetative cover. In humid and subhumid regions, however, heavy vegetative cover often obscures them.

Each soil group has its own set of characteristic elements, the proper use of which makes possible the identification of soils. The elements that should be studied closely for successful interpretation of wind-deposited soils are: land form, gully systems, gully shapes, "cat steps," pinnacles, drainage pattern, land use, vegetative cover, and color tones.

In general the loess pattern can be divided into three types: Great Plains, Palouse, and the Mississippi Valley. It may not be necessary for the trained observer to group loess patterns geographically because, in his study of the patterns, he will weigh each variation of the elements and judge accordingly. For this presentation, however, the loess pattern can be simplified by use of the physiographic division.

## Land Form

The loessial land form of the Palouse region (Washington) varies from moderately rolling plains to hills. The general land form of loess found in the Great Plains region is generally level, broken only by drainage, erosion scars, or a series of elongated parallel ridges. The land forms associated with the major streams of the Mississippi Valley (Mississippi, Missouri, Wabash, and Ohio Rivers) vary from very rolling near the streams to moderately rolling farther inland. In each of these three areas, the prominent features which constitute the relief are softly rounded; in many cases, they even suggest streamlining. The general appearance is soft and "silky" and strong parallelism between various hills often exists. Regardless of location, the land form is one in which the wind has played the major role in shaping the physical features. Figures 23 to 25 illustrate topographic characteristics of the three major loess deposits of the country.

Study of each of the three major silt areas might lead the observer to believe that the land forms show little similarity, especially when trying to find such elements as parallelism of hills existing in each area. However, a sizable mosaic viewed from a distance will show this parallelism. From a study of one or two prints, which may cover only a small area, certain elements may not be obvious because local erosion or stream dissection may have interrupted the formation of a clear pattern. Figure 26 is a stereopair of an isolated loess region on the Columbia River (basalt) Plateau. It is apparent from the amount of dissection that this area is rolling. The parallelism of the hills, together with the softly rounded slopes, indicates wind deposition. Figure 27 is an airphoto which illustrates the land form of the more rolling areas of the Palouse region. Study of the stereopair of such a small area does not necessarily reveal the parallelism of drainage systems or of hill areas but does permit close observation of the other elements of the pattern. The land form characteristic of the very flat to gently rolling areas of the Palouse is illustrated in figure 28. In these areas active erosion has been held in check and the typical erosional scars are not present. However, the weakly developed drainage systems that are visible show a similarity in plan to those of other loess areas. The main gully channels are parallel and the laterals are short, usually entering the gully channels at right angles.

The land form of the Great Plains loess is illustrated in figures 29 and 30 and in figures 36 and 37. Figure 29 shows the land form typical of the level areas which are not yet scarred by active erosion. The parallelism of hills and drainage systems, so characteristic of the Great Plains loess, is shown in figure 30. A considerable portion of the loess area of the Great Plains is in various stages of removal by erosion (figs. 36 and 37). When active erosion occurs such elements as pinnacles, "cat steps," and gully shapes are clearly visible in aerial photographs and can be easily studied. In general, the Great Plains loess occupies a level to gently rolling topographic position. When hills occur their main axes are closely related to the inter-hill areas, frequently resulting in parallelism of main gully channels. When erosion becomes extremely severe, as in the "dust bowl" regions, the land form is that of a highly dissected plain with occasional flat-topped remnants suggesting the presence of a former plain.

The land form of the loess along the Mississippi Valley is illustrated in figures 31 to 34. Figures 31 and 32 show the patterns typical of the upper and lower Mississippi River areas as found in Jo Daviess County, Ill., and Adams County, Miss., respectively. The loess patterns along the Missouri River, shown in figures 33 and 34, are in Woodbury and Plymouth Counties, Iowa.

The pattern of loess along the major streams in the Mississippi Valley varies more in land form than does the loess patterns of other locations. The topography adjacent to the stream proper is more rolling because the loess nearer the stream is deeper and the dissection is greater. As the loess becomes shallower inland from the streams, the land form becomes influenced by the underlying material and contains elements of the pattern of both materials.

## Drainage Pattern and Gully Systems

Another important element of the loess pattern is that of parallelism in the drainage systems or the large gully systems. The overall drainage pattern lying between parallel hills resembles a fish bone in plan. The main streams or large gullies are parallel; in some terrain, they may extend for miles in a nearly straight line. The main gully channels have short, steep, gully laterals that enter at right angles and create the fish bone appearance illustrated in figures 35, 36, and 37. This is the pinnate-type drainage pattern. In arid and semiarid regions the gullies and channels are often dry and support a sparse vegetation, while in humid and subhumid regions they are filled with heavy vegetation. The over-all drainage and gully systems of the more rolling areas also exhibit a parallelism that appears to be associated with the parallelism of the hills.

## "Cat Steps" and Pinnacles

Loessial silt naturally tends to develop vertical slopes in the erosional features; therefore, gully slopes are vertical. This generally holds true regardless of climatic influence although dense vegetative cover usually does not permit detailed inspection of such slopes in humid and subhumid regions. In the more rolling or gently rolling areas, "cat steps" are formed as a result of this natural vertical-slope-forming tendency. "Cat steps" are a series of vertical faced slides or soil sloughs occurring on slopes as illustrated in figure 38.

The silt pinnacle is another element that reflects the texture and the ability of loess to maintain vertical slopes. Figure 39 is a stereopair of an area in the Washington Palouse region in which active gullying has left isolated vertical columns of silt commonly known as pinnacles. These often are protected by clumps of brush or grass. Such features usually develop around the root system of plants. Note that pinnacles shown in figure 39 are more than 6 feet high.

## Land Use

Another element of the loessial pattern, related to man's activity, is land-use practices. A considerable part of the major wheat raising areas of the country (such as the Mississippi Valley, the Great Plains, and the Palouse region) is closely associated with wind-blown silt. A portion of the Palouse area normally receives only 5 to 25 inches of annual rainfall but extensive wheat raising is made possible in part by the moisture storing capacity of the soil. In the Great Plains and Palouse areas, the farms are large and greater acreages are devoted to single crops, as shown by the field patterns in airphotos of those regions. In the Palouse area, contour ploughing is practiced; this also is reflected in the field pattern. The field pattern of the Mississippi region differs from those of other areas because of topography, climate, and the average farm-size differential.

## Vegetative Cover

The native vegetative cover varies with the climate influence. This is reflected in the airphoto patterns. In arid and semiarid regions, there is a noticeable absence; in subhumid regions, heavy vegetative cover is confined to the valleys and larger gullies or in general to that land not being farmed; and in the southern regions or humid areas heavy vegetation abounds covering constructional gullies, valleys, and uplands. In the more humid regions, stereovision is of the utmost importance since the vegetation of the gully systems usually blends into that of the upland with little or no color contrast.

## Soil Color

In regions where it is possible to see the ground conditions through the vegetative cover, the soil color tones appear light grey to dull grey—never dark. This light color tone reflects the well-drained nature of silty soils. In areas where a "B" soil horizon has developed, the pattern reflects the increased clay content by a correspondingly darker color tone. This is more pronounced along the Mississippi Valley, where weathering has taken place at a more rapid rate.

# Chapter III.—SANDSTONE AND SHALE

This chapter is concerned primarily with the airphoto pattern of various sandstones and shales in the northwestern part of the country, chiefly those occurring in Montana and Wyoming. In discussing these patterns, the following chapters from Technical Development Report No. 52 are supplemented: Chapter II, Notes on Geology and Pedology, pages 5–19; Chapter III, Residual Soils, pages 20–33 (particularly pp. 22–26); Chapter VII, Non-Soil Areas, pages 72–75; Chapter VIII, The Principles of Airphoto Interpretation, pages 76–86; and Chapter IX, Airphoto Analysis of Residual Soils, pages 87–97 (particularly pp. 87–92).

The description of the origin, distribution, engineering problems, and general airphoto interpretation of sandstones and shales given in chapters II, III, and IX leaves little to be added as a supplementary discussion concerning the general aspects of this type pattern. However, subsequent to the completion of Technical Development Report No. 52, additional data in the form of airphotos, engineering test results of field samples, and numerous ground photos have been obtained of many varieties of the sandstone-shale pattern, particularly in Montana and Wyoming. Figures 40–64 illustrate many elements of this pattern in these two States. In some cases, the ground photos are accompanied by aerial photos to provide correlation between the two. Unfortunately airphotos of desired locations in Wyoming were not available.

With the airphotos in hand, the variations in the sandstone-shale pattern can be traced by application of the airphoto technique.

## General Aspects of the Sandstone-Shale Pattern

Sandstone and shale, and combinations of the two, can be identified from airphotos (regardless of location, climatic condition, or geologic age) because certain dominating or outstanding elements of the pattern will always be present. These dominating elements usually are supported by other elements which further identify the material. The range in variations of the pattern produced by these rocks varies with the relative thickness of the strata when interbedded, the relative position of the resistant to nonresistant layers, the dip of the strata, the climatic influence, and the lithologic features of individual strata. Such influencing factors make possible wide variation in a rock combination. The photo pattern of massive sandstone under arid conditions has the appearance of being more angular than massive sandstone under humid conditions. Weakly cemented sandstones do not create patterns similar to those representing harder, more durable sandstone. Furthermore, the pattern varies with the thickness and relative position of various strata to the extent that massive shales that would ordinarily erode away are held in place by a thin resistant sandstone cap. When the pattern is predominately that of shales, it often is possible to distinguish between clay and sand shales when variations are observed. Tilted strata show a pattern quite unlike that produced by horizontal rocks by creating variations in drainage pattern, vegetation, land use, and land form.

Successful airphoto interpretation of the sandstone-shale pattern and its variations depends on a study of the following elements: A land form controlled initially by the dip and lithologic characteristics of the strata; either a dendritic or trellis-type drainage pattern; angular or rounded gully slopes in the erosional features; a vegetative pattern that depicts climatic influence or conditions; and certain man-made features. These elements are closely related and one or two of them often will suggest the presence of others. Figures 40 to 45 illustrate sandstone, shales, or combinations of these rocks occurring under some of the climatic ranges in this country. These airphotos have been reproduced for stereovision to facilitate study and comparison of these variations.

## Land Form

The land form of sandstone and shale combinations generally depends more upon the dip and lithologic characteristics of the strata than on any other influence. Alternate beds of sandstone and shale, when occurring as flat-lying strata, resemble a contour map, with vegetation, land use practices, or exposed rock ledges delineating the outcropping strata. In arid and semiarid regions, the layers are outlined by exposed sandstone layers occurring as pronounced bluffs separated by sloping shale layers. Often, especially in semiarid or subhumid regions, vegetation outlines the various strata adding to the countour-like appearance of the pattern. In arid regions where sandstone is the major rock type, the land form is angular with deep canyons and high mesas predominating. With increasing amounts of shale, the land form becomes more rounded with mesas and canyons still the predominating feature but being somewhat softened in local relief. In humid regions, massive flat lying sandstones and shales still retain their angular and rugged characteristics; however, the relief is softened by heavy vegetative cover and a deep soil mantle. Erosion is not as severe, partly because of the retarding action of the vegetative cover on runoff. Weakly cemented sandstones in a humid climate produce a more rounded topography than sandstones cemented with more resistant material. In arid regions, dissection in shale strata is severe, with colorful badlands occurring frequently. Clay shales produce land forms having rounded slopes while sand shales produce a land form having more angular slopes in the erosional scars.

The land form of tilted strata is related to the amount of tilt, the lithologic features of the various strata, and the respective positions of weaker and stronger rocks. Such physical features as cuestas, wind gaps, water gaps, and hogbacks associated with tilted strata are easily discernible in airphotos. Tilted sandstones and shales in an arid region usually result in a land form that is more angular in relief than sandstones and shales in a humid region. In arid regions the harder rocks, unless water-bearing, are bare and angular with little or no soil cover. In humid regions the sandstones have weathered to produce a sand-clay soil mantle, well-suited to heavy vegetative cover, which adds roundness to the sandstone land forms.

## Drainage Pattern

The drainage pattern of flat-lying sandstones and shales, and combinations of the two, is dendritic with numerous angular stream bends occurring wherever resistant strata are encountered or crossed. Streams and gullies flowing entirely in the harder sandstone rocks occupy narrow often gorge-like, channels which are not free to meander. In such instances the valleys are narrow and have steep sides. The streams and gullies flowing entirely in the softer shales are free to meander in their valleys. Such valleys usually are broad and contain some alluvial deposits. In shale areas, the valley sides are more softly rounded.

The drainage pattern associated with tilted strata is trellis-like, regardless of climatic condition. The airphotos reveal the influence of the angle of tilt on the topography through examination of erosional scars as well as by observation of relief.

## Shale Gullies

The gullies and their related cross-section (shape) and gradient depend on the types and dips of the rocks in which they are positioned and on the climatic conditions. Gullies associated with clay shales generally have softly rounded shapes and, when in flat-lying strata, have long shallow gradients. One noted exception to this general principle, however, is the clay-shale strata occurring in arid regions in which infrequent but sudden intense rainfall is the chief erosive force. In such instances, local gullies will be so scoured by the erosive force that rounded slopes do not form. The problem of the interpreter is to decide whether such erosive features are recent in nature. In humid regions where rainfall is more evenly distributed throughout the year, gully shapes are more reliable as indicators of shale textures.

## Vegetative Cover

In general, the vegetation depends on the climatic influence. In arid regions, the heaviest vegetative cover is confined to the outcrops of the water-bearing strata which adds to the contour appearance of the flat-lying sediments. In humid regions, it is difficult to detect changes in rock when the entire region is blanketed with a heavy vegetative cover. A change in slope, however, will usually accompany a change in rock type which can be seen by close stereoscopic study.

## Man-Made Influences

In areas of alternate layers of hard and soft rocks where the slopes permit cultivation, it is often possible to separate strata on the basis of man's activity. In such instances the more resistant sandstone rocks will be left for timber, since the soils are relatively rocky and shallow, while the softer shale rocks may be in cultivated areas. This produces a very broad contour effect on the airphotos which consists of alternate bands of vegetation and cultivated fields. It is of some importance because the observer can study gully shapes in the bare areas. The same principal conditions hold true in the arid and semiarid regions; however, they usually are on a larger scale.

# Chapter IV.—IGNEOUS ROCKS

This chapter discusses a few of the airphoto patterns produced by two major primary rock types of widespread occurrence throughout the western mountainous regions—intrusive and extrusive rocks. On the engineering soil map accompanying Technical Development Report No. 52, such rocks and rock areas are classified as intrusive (chiefly granites) and extrusive (chiefly basalt and lava). The areas indicated as "rough and stony" contain many igneous rocks which are too rugged and rocky to be of importance as soil-forming materials. Metamorphic rocks such as gneiss, schists, slates, and other similar materials are not discussed because of the lack of sample airphotos for pattern illustration.

The study of the various igneous rocks is complex and it is beyond the scope of this report. In addition, little field work has been done that is pertinent to the actual correlation of airphotos with definite types of igneous rocks and their mineral constituents. The chief purpose of this chapter is to show that igneous rocks do create, and develop, types of airphoto patterns which can be identified by following the same techniques or principles of photo evaluation as applied to other types of rock and soil materials. Figures 65 to 81 are airphoto and ground views illustrating the igneous rock formations.

In general, this chapter supplements the following chapters of Technical Development Report No. 52: Chapter II, Notes on Geology and Pedology, pages 5–19; Chapter III, Residual Soils, pages 20–33 (particularly pp. 31–33); Chapter VII, Non-Soil Areas, pages 72–75; Chapter VIII, The Principles of Airphoto Interpretation, pages 76–88; and Chapter IX, Airphoto Analysis of Residual Soils, pages 87–97 (particularly pp. 93–97).

There are two types of igneous rocks: (1) intrusive rocks, formed by the cooling of hot magma within the earth's surface; and (2) extrusive rocks, formed by the cooling of hot magma at or on the earth's surface either as a volcanic eruption or as a large lava flow.

## Intrusive Rocks

The intrusive rocks are geologically classified according to the form they occupy—such as batholiths, laccoliths, dikes, sills, plugs, and bosses. All intrusive rocks were formed by hot magma under pressure being forced upward through cracks, joints, or structurally weak sediments. Severe warping often accompanied such action. Since the intrusive rocks do not reach the surface except by subsequent erosion, they cooled slowly and as a result are coarse grained and composed of large mineral crystals. The original mineral constituents contained in the magma will be the controlling factor of the type rock formed; thus the rocks are named according to the predominant mineral.

The batholith is perhaps the largest intrusive rock mass; it may have an exposed area of thousands of square miles. Batholiths usually are composed of coarse-grained granite and often are the core or the backbone of great mountain ranges. Such areas are usually flanked with wide bands of metamorphic rocks; folding and faulting of the adjacent metamorphosed and unaltered rocks are common.

The laccolith type of rock is usually composed of coarse-grained granite also. Such a rock mass forms when a mass of molten magma separates various strata of sedimentary rocks by an arching action; thus, laccoliths are believed to have a flat bottom and an arched top. They are considerably smaller than batholiths.

Dikes result from subsequently cooled magma which has filled cracks, joints, or fissures in other rocks. Since dikes cool rapidly, they are usually fine grained and porphyritic in texture. The most common of these rocks are called rhyolite, trachyte, dacite, basalt, and augite—all porphyry.

Sills, often called sheets, occur as thin flat sheets or layers of igneous material spread between the layers of sedimentary rocks. Rocks found in sills are also porphyritic and are commonly called granite, syenite, diorite, gabbro, and pyroxenite.

The land form or igneous rock mass known as a "plug" represents the remains of a filled volcanic channel or conduit.

A boss, or stock, is a term applied to a definite shape or land form rather than to its origin. Such a land form consists of rounded hills or knobs of granite which appear to be well polished.

## Extrusive Rocks

Extrusive rocks are those igneous rocks which have cooled on the surface, either as a lava sheet from a quiet eruption or as volcanic ash or volcanic breccia, when deposited on the earth's surface by violent volcanic activity.

The lava flows, or sheets of molten lava, are commonly known as basalt, even though, mineralogically there may be several types. In general the basalt group of rocks are dark in color, basic, form a columnar structure, and are fine grained. In many areas the basalt layers, or lava flows, are separated by layers of soil formed between periods of igneous activity.

The more common terms associated with the volcanic-deposit class of igneous rocks are pumice, ash, volcanic bombs, volcanic breccia, tuff, craters, and cinder cones.

## Soils

Soils are the result of the weathering of rocks and rock minerals. An igneous rock buried beneath the surface is stable because it is adjusted to the surrounding conditions. As soon as the rock is exposed to the atmosphere by erosion it is in a new environment; thus, the rock becomes unstable and the process of weathering commences. Weathering is accomplished by chemical means (decomposition), by mechanical means (disintegration), or by a combination of both. Chemical weathering includes actual mineral decomposition by the processes of hydration, carbonation, oxidation, and hydrolysis. Mechanical weathering includes disintegration by wind and water, abrasion, thermal expansion and contraction, growth of root systems, and the pressure of ice within the rock voids. The rate at which these agencies act on rocks depends on the climatic influence, topographic position, ground slope, and general altitude. The type of soil developed depends largely on the mineral composition and crystalline-rock structure as well as on the agencies of weathering. In general, the granular soils are the result of disintegration and the nongranular residues are the result of decomposition of the soluble, or easily altered, minerals forming finer-textured materials.

## Airphoto Patterns

The airphoto pattern of an area, if properly evaluated, will indicate all or a portion of the sequence of geologic events which occurred in the area up to the present. It may not be possible to obtain the facts by a study of a small number of photos giving only limited areal coverages. The structural features or alinement may not be apparent or readily discernible in the photos. This varies with the area being studied. Considering only the rock patterns, the accuracy, ease, and speed of prediction vary with the presence of certain dominating physical features. As an example: the presence of sinkholes brands an area as being composed of soluble rocks, generally limestone. Shales and sandstones are more difficult to identify, because other elements must be studied and each element must be evaluated properly before a decision can be reached. (See ch. III, Sandstone and Shale.) In such instances the shape of gullies, shape of hills, drainage pattern, and topography must be studied before the sandstones and shales can be separated. Tilted sedimentary rocks can be identified as such merely by the lineal arrangement of the upturned strata and the resulting drainage pattern. Separating the three sedimentary rocks (limestone, sandstone, and shale) involves detailed study of the elements characteristic of each pattern. In a similar manner, the patterns produced by igneous rocks contain definite elements which, when properly evaluated, will identify them as being igneous.

### Extrusive Rocks

The extrusive rocks considered in this chapter are limited to lava flows, basalt flows, and volcanic ash (pumice).

Volcanic areas are perhaps the easiest of all the extrusive materials to identify, especially when such land forms as cinder cones and small lava flows are present. The shape or land form of a cinder cone, with the ever-present crater, is sufficient to identify this type of deposit. The drainage pattern is radial with the gullies radiating down the slopes. The gully cross-sections are box-like with vertical sides and flat bottoms. Often flows of another period of activity in the vicinity of the cones can be distinguished.

Lava flows, regardless of magnitude, will always exhibit the pattern element of directional flow. Such may not be apparent in one or two pictures when considering a flow on a large scale; if a sufficient number of photos is available, however, the flow pattern becomes evident. Successive stages in flow advances often can be distinguished by the wrinkled appearance of the patterns. The depth of soil developed on such land forms will depend on the climatic condition. In general, the volcanic areas in arid regions are rocky and contain little or no soil development while those in tropical, or even humid, regions are mantled with a deep residual soil.

The term basalt as used here refers to the major lava flows (those in the Columbia Plateau of Washington, Oregon, and Idaho) which often attain a total thickness of 4,000 feet. On such a scale, the element "flow marking" of the photo pattern is frequently absent. Close inspection of surface details may reveal such elements as polygons, columnar structure where exposed in canyons or gorges made by erosion, scant vegetation, rocky surface texture, and jointing. Often such areas are so barren, devoid of vegetation, and rocky that they are referred to as "scab lands." The large basalt areas are usually stratified in that they are structurally composed of numerous layers of lava flows separated by soil representing interbasalt stages. The patterns of such areas illustrate this condition only where erosion has carved deep channels or gullies in the area. The various layers of basalt then appear as vertical columns separated by softer slopes of the interbedded soils.

### Intrusive Rocks

This discussion is concerned primarily with granites occurring in the batholithic and laccolithic intrusions. The important consideration is the use of airphotos to separate the various rocks and to classify them into a general rock type: igneous, sedimentary, or metamorphic. A boss, laccolith, or batholith cannot be identified easily from an aerial photograph.

The airphoto pattern produced by sedimentary rocks follows certain definite or standard identifying elements that seldom vary for any one rock type—or rock combination—at a given tilt. Increased tilting produces changes in certain elements which are readily discernible in the photos. The intrusive igneous rocks generally produce a pattern wholly different from the sedimentary rock pattern. By way of comparison there is little or no lineal arrangement of such items as drainage channels, gullies, and outcrops; no dip nor strike, and there are no contoured outcrops. This is due to the fact that igneous intrusions usually are so large in mass and in areal extent that they have a nearly uniform composition throughout their mass. The airphoto pattern of a large igneous area shows a striking uniformity in relief, gully shapes, general repetitive type land form, and drainage pattern. The drainage pattern of most igneous intrusions is random—dendritic or unobstructed by varying rock conditions. Main streams are seldom parallel; even the gullies have a random flow pattern. Quite often the airphoto pattern of granite will show a system of cracks or joints which have been produced partly by the cooling and partly by the weathering characteristics. This element appears on the photos as a fine angular network of "hairchecks"; these often are large enough to cause local angularity of gullies or drainage systems.

The weathering of granite to produce soils depends on the mineral constituents and the climatic influences. If a granite core of an uplift consists of easily altered minerals or of minerals loosely bound together, the core of the uplift may be reduced sufficiently by erosion to occupy the topographic position of a basin (Laramie Mountains, Wyo.). If the granite is composed of minerals which are resistant and strongly bound, the core will be the prominent feature of the uplift. Small intrusions always are accompanied by the upturned layers of sedimentary rocks which appear as "leaves" surrounding the base of the granite core.

# Chapter V.—WATER-DEPOSITED MATERIALS

Water-deposited materials in the continental United States represent a large percentage of the total surface area of the country. Exclusive of glacial association, water-deposited materials include deposits of the Coastal Plain, the Great Plains, valley fill of the Basin and Range, Tertiary lakes, Pleistocene lakes, and a variety of stream alluvium.

This report is confined to water-laid materials including valley-fill portions of the Basin and Range province in Nevada, Utah, southern California, southern Arizona, and southern New Mexico; also the Great Plains Rocky Mountain outwash materials extending from northern Nebraska to south central Texas. This chapter covers typical airphoto patterns of water-laid materials found on the northern portion of the Great Plains and in the valley-fill materials of Oregon, northern California, Nevada, and Utah. Included in this chapter are descriptions of airphoto patterns of water-laid materials.

## Materials of the Great Plains

The Great Plains area includes a broad expanse of land extending from the Mexican border directly across the United States and Canada to the Arctic Circle. The eastern limit in this country is an approximate north-south line extending from central North Dakota into central Oklahoma and central Texas. The western boundary may be considered as the Rocky Mountains, excepting the Wyoming Basin which might be considered as a portion of the Great Plains.

Large quantities of Rocky Mountain outwash materials presumably have been deposited over most of the Great Plains. However, in the northern region, particularly North and South Dakota, Montana, and in the Wyoming Basin, the outwash materials have not been deposited or have been denuded by the processes of erosion. Similarly, the Piedmont of Colorado has been partly denuded, and in all probability the eastern portion of the Great Plains has had this mantle removed. The outwash mantle proper, still very extensive, extends from northern Nebraska to central Texas.

The water-deposited materials constituting the Great Plains mantle are semiconsolidated silts, sands, and gravels which were deposited by rivers, flowing in an easterly direction, carrying sediments from the Rocky Mountains.

The oldest of these materials is identified geologically as Arikaree, and the most recent deposition has been mapped as Ogallala. The Arikaree consists largely of sandstones weakly cemented with calcium carbonate; the Ogallala is frequently described as "grit loam and sand." The surface soils in both instances are frequently mixed with wind-deposited materials—silts and sands.

## Materials of the Filled Valleys

A considerable part of the western United States is, in general, a region of valleys and mountains; the mountains are being eroded and the valleys are being filled with debris. Since these filled valleys, which often are quite extensive, are the only reasonably flat areas in an otherwise mountainous area, they are important for locating airfields, highways, and railroads. The Willamette Valley of western Oregon and the Great Valley of central California, previously mentioned, are important examples of filled valleys. The entire Basin and Range province of Nevada, western Utah, southern California, southern Arizona, and southern New Mexico likewise form a region of level valley fillings lying between mountain ranges. Valley-fill materials are primarily water-deposited; therefore, the materials range in textures from lacustrine silts and clays to coarse gravels and boulders. The wide range of soil textures presents an airpohoto pattern that can easily be recognized.

## Materials of Tertiary Lakebeds

Fresh-water deposits of Tertiary age are to be found in many regions of the Western States. These lakebed materials are similar to the more recent valley fillings, with the exception that they are occasionally consolidated—diatomaceous earth is common. Basalt flows and other volcanic materials, including volcanic ash, are frequently encountered in Tertiary lakebed regions. Because these areas frequently are the logical locations for airports and highways, the materials are important.

## Pleistocene Lakebeds

Lacustrine silts and clays, granular terraces, and ancient beach ridges of the west are widespread in the Basin and Range province. The Basin and Range region is primarily a basin without an outlet to the sea; during glacial times it contained large bodies of water. When evaporation exceeded flow into the lakes they gradually dried up and became extensive flats. Great Salt Lake is a remnant of one of the large inland lakes of Pleistocene times. Topographically the lacustrine regions are extremely flat and cover areas in Nevada, Utah, southern California, Arizona, and New Mexico. The soils are usually very plastic.

In contrast to these lacustrine materials, granular beach terraces are to be found along the mountain slopes of the Basin and Range province. These terrace remnants are frequently of sufficient size for airport location and, in many instances, the materials are used as commercial aggregates. The terraces are readily identified on aerial photographs.

## Airphoto Patterns—General

The ease of airphoto interpretation of water-deposited materials depends on many factors including age and erosional history; texture of the overburden; degree of induration, consolidation, or cementation; topographic position; and climatic influence. Because the water-laid materials discussed in this chapter are of various ages ranging from Tertiary times to recent, the patterns are not consistent and the various elements cannot be compared. Even though the water-laid materials of the various geological ages cannot be compared element for element, each has pattern elements which indicate the manner of deposition. The most common element of water-deposited materials is flat topography; in highly dissected areas where erosion has nearly destroyed the once level upland, the flat topography may be represented by flat topped mesas or buttes. In such areas other elements, such as erosional features (gully shapes), must be evaluated before textural predictions can be made. The more recent deposits, geologically speaking, can be interpreted more easily because many of the elements are well developed and have not been destroyed by severe dissection. Signs of current activity are well preserved.

The airphoto patterns here considered include the following: Recent granular mantle of the Great Plains; the Tertiary deposits of the Great Plains (Ogallala and Arikaree); the filled valleys, commonly associated with the "Basin and

Range"; the Tertiary lakebeds; and the Pleistocene lakebeds. These patterns are illustrated with airphotos and ground views.

For purposes of airphoto identification and description, the Great Plains materials can be grouped into four general categories: (1) Bedrock materials including shales, sandstones, and interbedded sandstones, shales and limestones from which the Tertiary mantle has been removed; (2) sedimentary rocks mentioned above—containing shallow or isolated remnants of the Tertiary mantle which, in effect, are denuded areas representing a transition between the areas of bedrock outcrop proper and those covered with a deep Tertiary mantle; (3) the large expanse of land area which contains a cover of the Tertiary mantle and a covering of wind-blown sand and silts; and (4) recent stream-deposited materials which might be considered as river alluvium, and other recent fluviatile deposits.

The airphoto patterns of the recent fluviatile outwash deposits contain elements similar to those associated with granular outwash, granular terraces, and granular alluvium. This pattern represents the most recent deposits on the Great Plains. The land form generally is that of a level plain crossed by an occasional recent stream valley. Current scars and other flow marks comprise the surface pattern. Where major valleys or streams cross the plains, steep sides predominate if the surface mantle is granular. Increasing amounts of fine materials tend to flatten the slopes but if small gullies occur on the face of the valley sides, the gullies are short and V-shaped. The color tones generally are light gray with a subtle speckled or mottled appearance. The mottling is typical of granular patterns and is associated with small infiltration basins. Figures 82 to 86 are airphotos and ground photos illustrating the recent Great Plains mantle.

The materials in the Great Plains-Tertiary Mantle group are partly cemented by calcium carbonates and are, in general, soft calcareous sandstones, limestones, and shales. The airphoto patterns of these bedrocks are somewhat typical of other sedimentary rock patterns. The region contains large expanses of Pierre Shale found predominantly in the area surrounding the Black Hills, Tertiary sandstones and shales found primarily in Montana and Wyoming, and redbed shales with some sandstones found in Oklahoma and Texas. Either the Tertiary mantle has not been entirely removed or, when the remnant exists, the rock pattern is partially obliterated by overlying materials.

The airphoto pattern of the Tertiary mantle proper is varied because the textures of the surface soils vary from silty clay to silts and sands. At the transition between the denuded portion and the overlying mantle, important changes in pattern are to be found. The erosion is severe and is somewhat representative of badlands. The headward erosion produces fine dendritic-like gullies which are in striking contrast to the pattern of the adjacent uplands. The mantle pattern varies somewhat. The over-all picture is one of flat topography, faint indications of old drainage channels, many undrained depressions or "buffalo wallows," and a remarkably regular pattern produced by land use.

The patterns of the Arikaree and Ogallala areas rarely exhibit the more common water-deposited pattern elements; this may be because of their age, induration, or cementation. In areas where the Arikaree occurs, the deposits either have been covered by recent wind-swept sand and silt or they have been denuded and dissected; thus partially—if not completely—destroying the once level upland surface. The surface pattern is characteristic of either wind-blown materials or of a dissected plain with mesas and buttes being the predominant topographic feature. Figures 87 to 94 are ground views and airphotos which illustrate the pattern of this material.

The airphoto patterns associated with valley-fill materials usually indicate the many geologic processes necessary to the deposition of such materials. An airphoto often contains a portion of an uplifted series of rocks which are being eroded and the materials are transported to the valley floor as fluviatile deposits. The uplifted rocks are characterized by lineal arrangement, steep and rugged topography, and trellis drainage features. The gullies discharging onto the valley floor build alluvial fans. In such instances the mountains are being buried in their own alluvium, creating a valley pattern with a series of large alluvial fans scoured with flow markings. The coarse materials generally are deposited near the foot of the uplifted slopes. Where recent gullying occurs on the alluvial fans, textures are indicated by studying gully shapes. Figures 95 and 96 illustrate some valley-fill situations. Airphoto interpretation notes accompany appropriate figures.

The Tertiary lakebeds and Pleistocene lakebeds are represented, in many instances, by elevated terrace remnants; others are present-day lakes, the most important of which is the Great Salt Lake. No aerial photographs accompany this report to illustrate this pattern. A few ground views, however, illustrate the various land forms, as shown in figures 97 to 99.

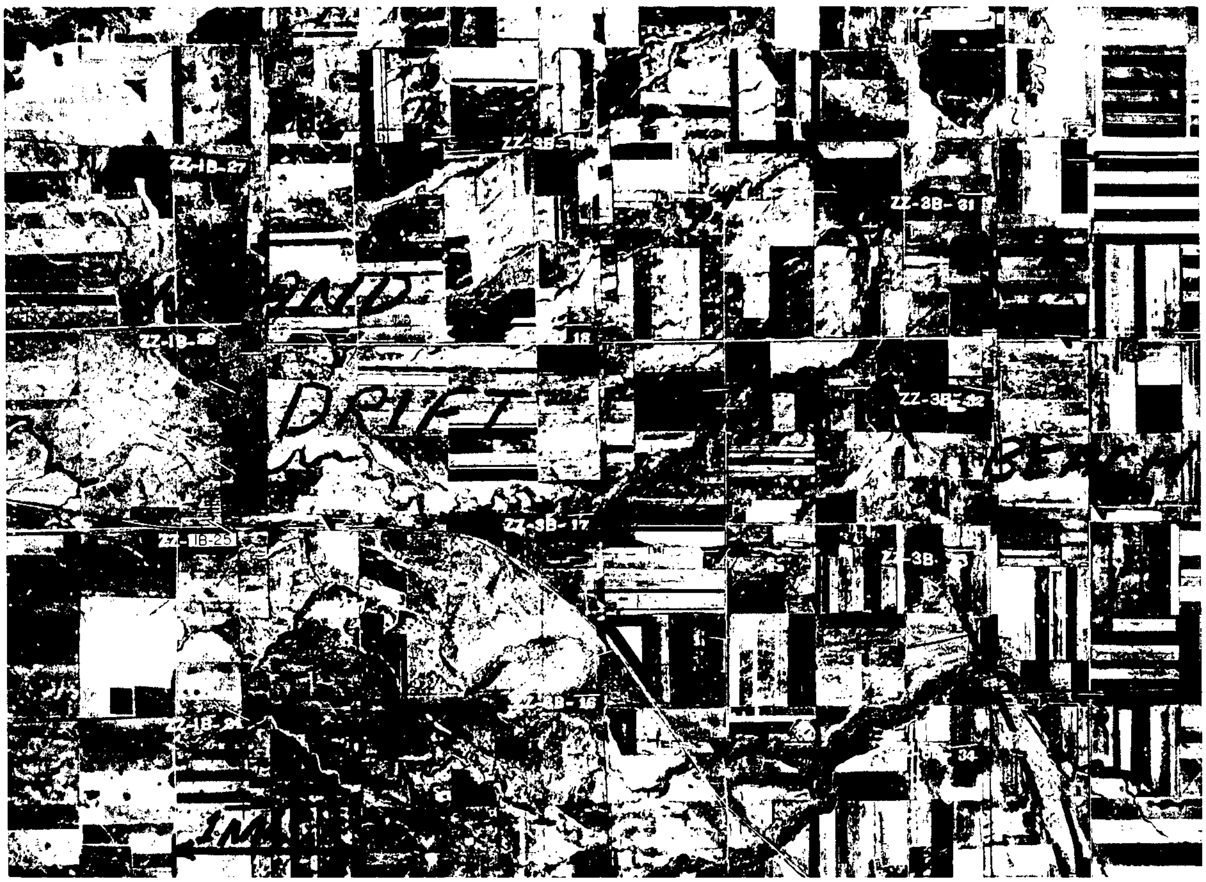


FIGURE 1. *Glacial Drift and Lake Terraces of Agassiz.* This mosaic is one of a series illustrating the various lakebed patterns associated with glacial Lake Agassiz. Part of the mosaic represents glacial drift and the remaining part is that of a shallow, semigranular beach or lake terrace. This is typical of the shores of glacial lakes in this region. Erosion has removed upland material which was carried through gullies. (Note the gullies draining into the former lake.) The material was sorted according to grain size with the coarse material being deposited first (near the shore). The material nearest the shore was reworked and was redeposited in the form of ridges and beaches by the action of waves. The beach or low-lying lake terrace consists of shallow reworked sand and gravel which in some instances is deep enough to create a well-drained airphoto pattern. Note the difference in the land-use pattern of the two areas as shown by the field pattern.

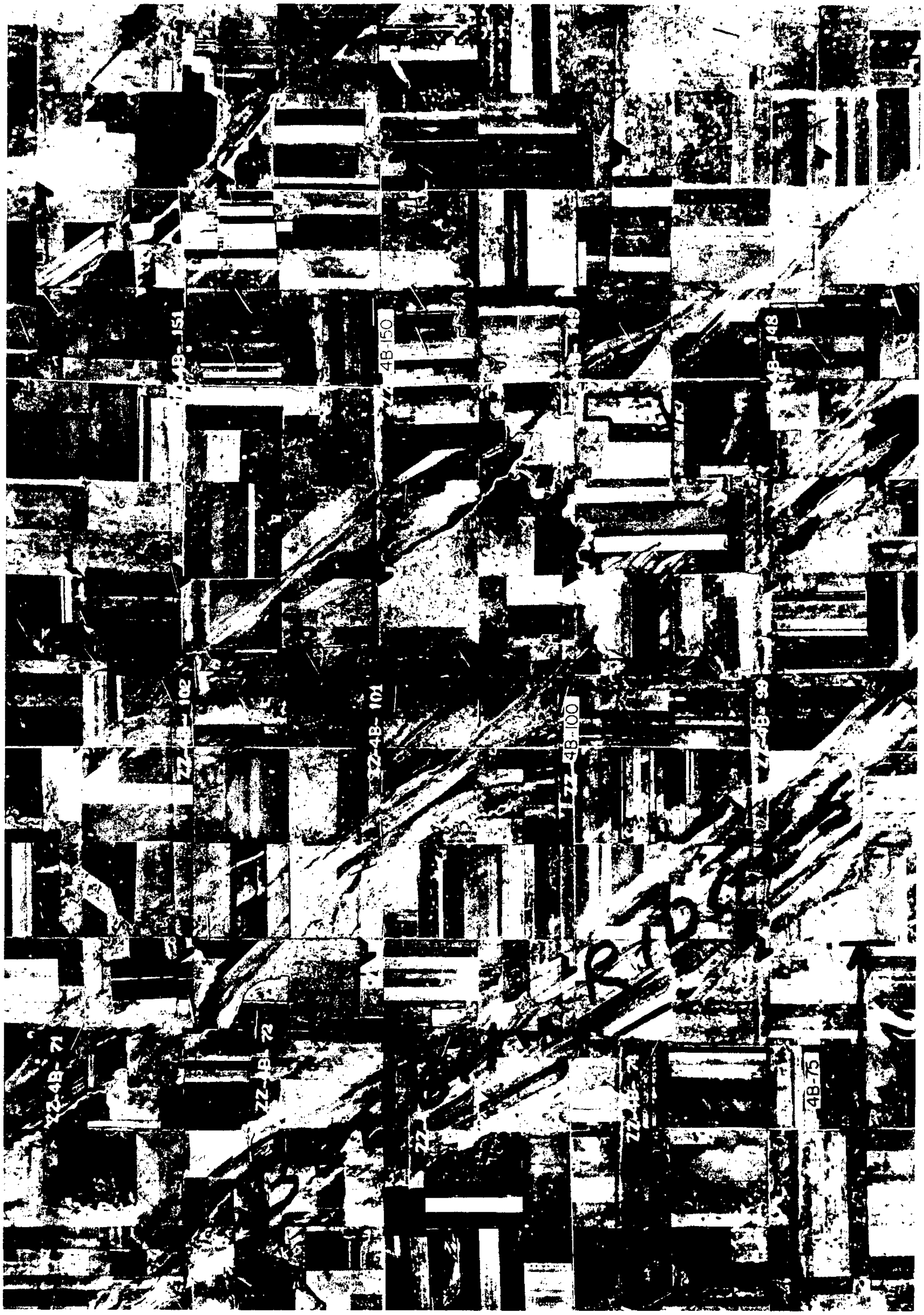


FIGURE 2. *Beach Ridges of Lake Agassiz.* Airphoto mosaic of a series of wave-formed beach ridges (extending from upper left to lower right in the photograph). This pattern is important because it shows granular material in the ridges. Fringing, glacial-lake terraces and beach ridges often are the only sources of granular material in a particular area. Figure 3 is a ground view of a beach ridge in Grand Forks County, N. Dak.

FIGURE 3. *Ground View of Granular Beach Ridges Associated with the Edges of Glacial Lake Agassiz.* Such ridges were probably formed by waves which reworked the granular material during periods of changes in lake elevation.

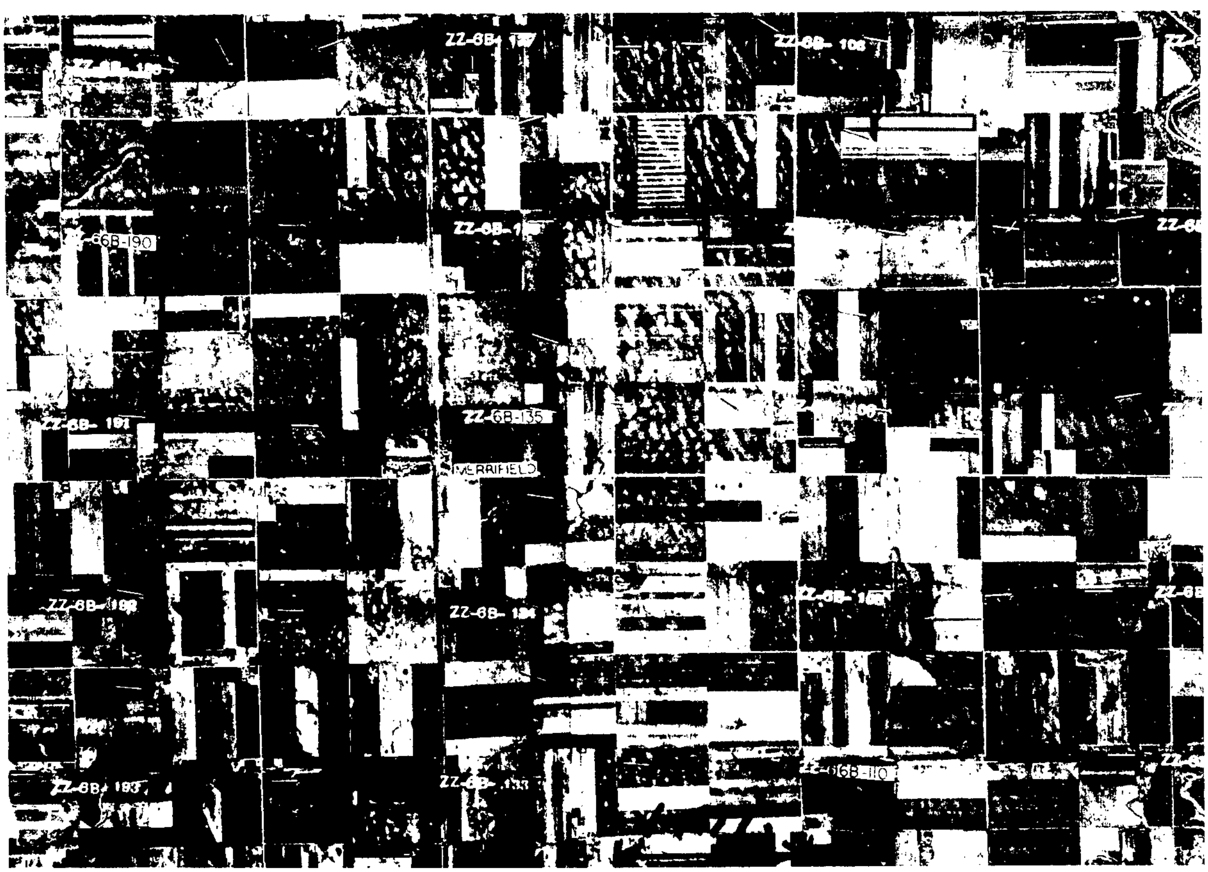


FIGURE 4.—*Lacustrine Silts (organic).* This mosaic contains the characteristic pattern of deep organic silts when covered by a deep organic topsoil (Lake Agassiz region). The soil consists of 12 inches of organic silt on deep silt. The light-colored parallel streaks are low ridges of silt, with a shallow organic soil cover. The relief of these ridges is slight, often less than a foot or two. Figure 5 shows an exposed profile of this condition.

FIGURE 5.—*Lake Agassiz Silt.* This is an exposed profile of deep silt associated with the silt portions of Glacial Lake Agassiz.

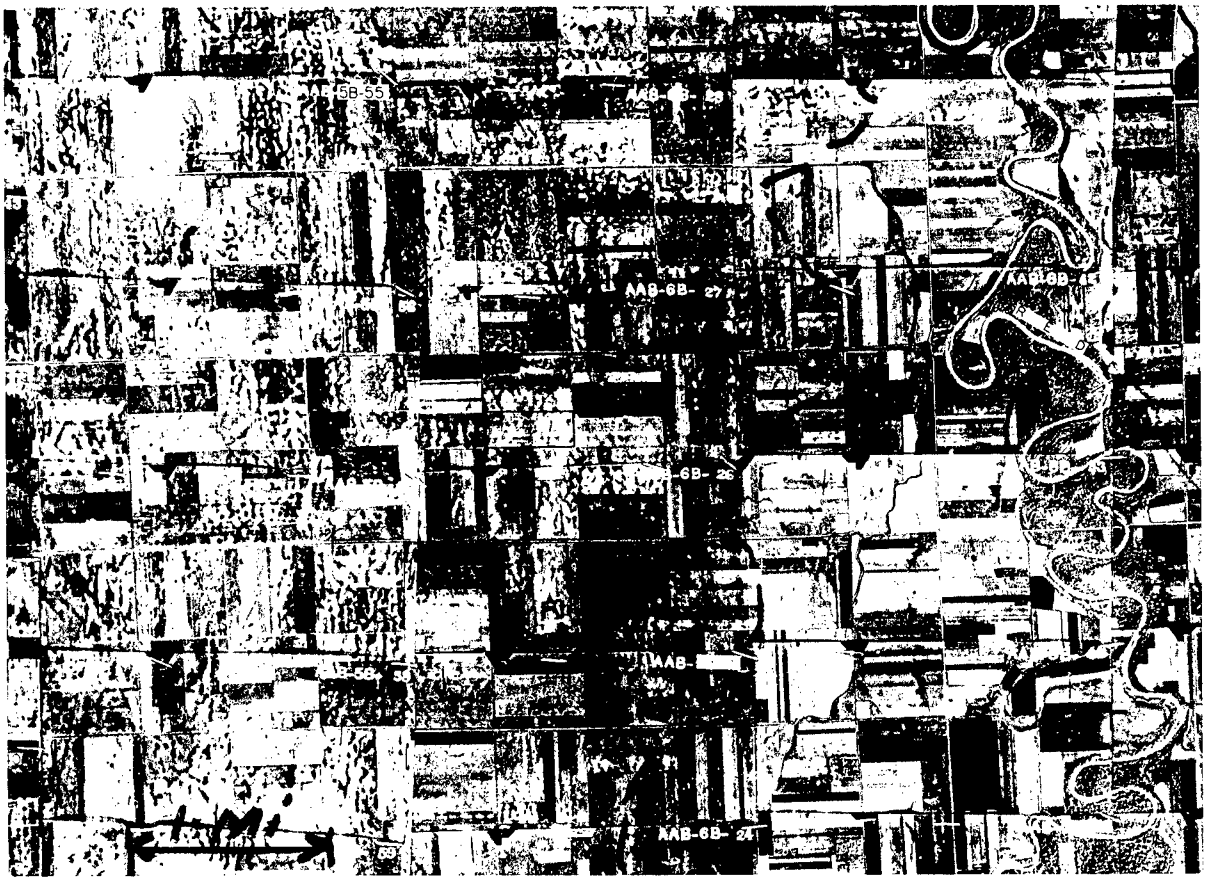

FIGURE 6.—*Plastic Lacustrine Clays (deep organic topsoil).* The left half of this area exhibits the pattern characteristic of organic lacustrine clays. The organic topsoil is approximately 20 inches deep, and when dry, contains long deep shrinkage cracks. The area adjacent to the Red River (right half) consists of a superficial cover of recently deposited silt consisting of a broad, low natural levee that has been built up in recent times. This is indicated by the obliteration of the original-clay pattern by silt as shown on the left side of the photo. The gullies draining into the river are confined to the silt cover, the character of which shows the presence of a porous, fine-grained material on an impervious clay. The light-colored area adjacent to the river also illustrates this levee formation. The absence of sand bars at the bends in the stream indicates the fine texture of the material being carried in this aggrading stream. The absence of heavy vegetation shows the climatic influence in this area. Note the reversal of color of the streaks of this pattern (black is clay; white is alkali influence) as compared to the streaks of figure 4 (white streaks are silt). Figure 7 illustrates the topography of this flat lakebed area.

FIGURE 7.—*Alkali Depression.* Note the vegetative change associated with this alkali spot. (The man is in the center of the alkali depression.) Such depressions occur in plastic clays of lakebed regions where evaporation is higher than precipitation. Alkali spots can be detected in airphotos by the change in vegetation and general light color tone. Note the flat topography and the absence of trees (Fargo, N. Dak.).

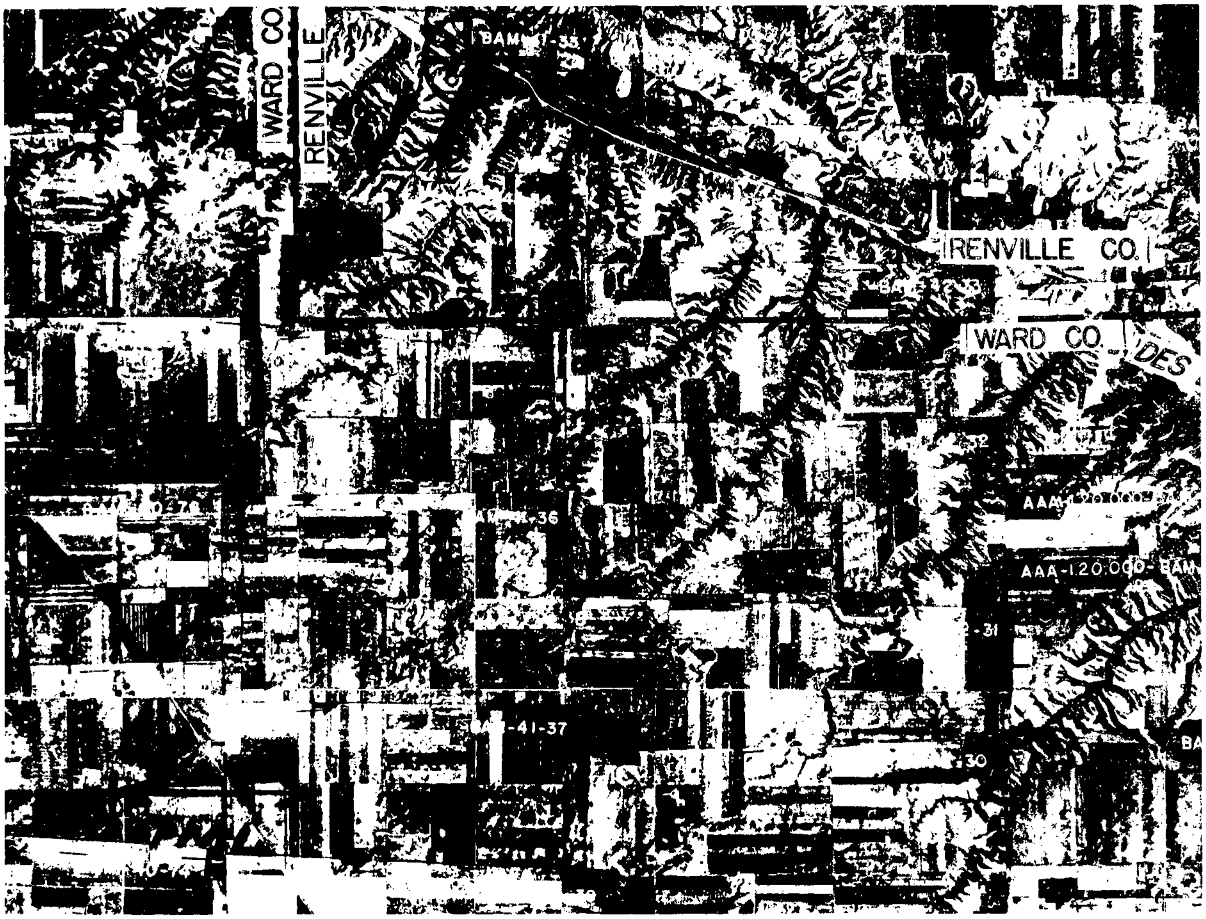


FIGURE 8.—*Glacial Lake Souris.* This mosaic is typical of the airphoto pattern of the Souris and Des Lacs River Valley which drains glacial Lake Souris. This stream has cut a broad channel or valley in the lakebed (fig. 9). These streams are degrading while the Red River is aggrading. The stream marks the boundary between the lakebed proper and the southern shore which fact is clearly indicated by the numerous gullies (coulees) flowing northward into the river and the absence of south-flowing gullies. Granular material occurs frequently as terraces in the stream valley and at isolated spots along the valley walls, all at levels below the lakebed proper.

FIGURE 9.—*Souris River Valley at Minot.* Ground view of the deep river valley carved in the bed of glacial Lake Souris. Note the level horizon line across the valley; this is the lakebed proper. Also note that the heavy vegetative cover is confined to the valley floor.

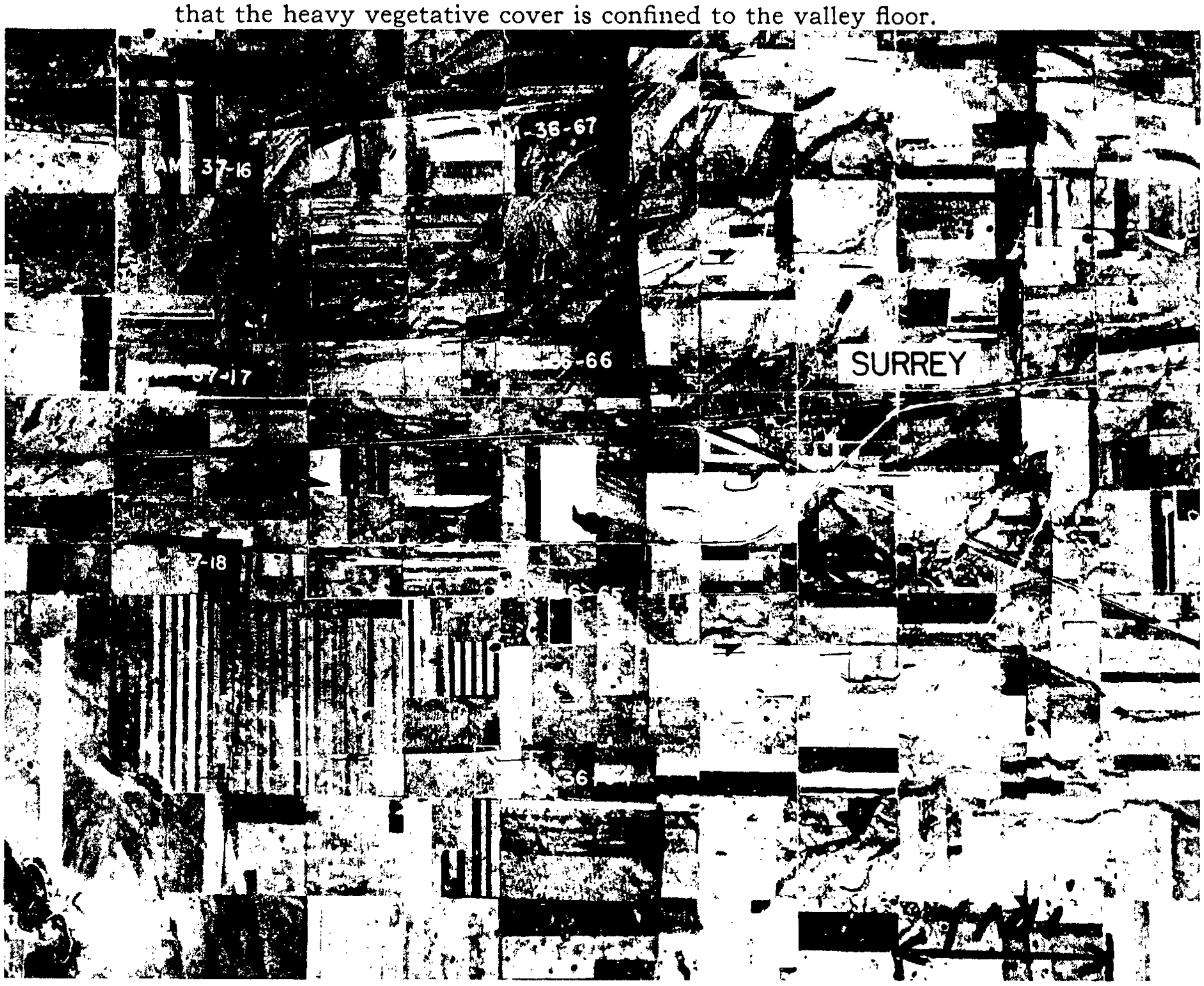


FIGURE 10.—*Current and Channel Scars in Lake Souris.* The numerous channel scars occurring in this area illustrate the intense glacial activity in this former lake. Such vigorous current action is usually accompanied by deposition of large amounts of granular material. The surface of the lakebed in this region contains granular deposits. Detailed examination of stereo-matched photos makes it possible to locate such deposits.


FIGURE 11.—*Peat and Muck in Lake Agassiz.* This lakebed pattern represents a portion of Lake Agassiz north of Red Lake in Beltrami County in which muck and peat bogs abound. The directional trend is indicated by vegetative influence due to the balance between vegetation, moisture, and topographic position. A considerable portion of this area is in a swampy condition.

FIGURE 12.—*Glacial Lake Maumee.* This photo shows the airphoto pattern typical of glacial Lake Maumee which is that of deep lacustrine clay and silty clay. The dark areas are slightly depressed, contain greater quantities of organic material, and have a high ground-water table. Note the gully; gullies of this type are definite indicators of lacustrine soils. The topography is flat, such as that of Agassiz and the portion of Souris not yet reduced by erosion. The topsoil is organic and of varying depth, depending on the topographic position. The subsoils consist chiefly of plastic clays and silty clays. Glacial Lake Maumee also contains a series of fringing granular beach ridges, some of which serve as locations for major United States highways.


FIGURE 13.—*Lakebed in an Illinoian Glacial Drift Area.* This southern Indiana lakebed is characteristic of the many swampy, undrained lakebeds of glacial origin. The lacustrine soils are deep silts and silty clays, gray in color, and highly mottled. The characteristic feature of this pattern is the sharp contrast between lakebed and upland—indicated by the change in vegetation, active upland erosion. dark gray to black lakebed color, and heavy growth of timber. These lakes rarely exhibit beach lines or terraces.

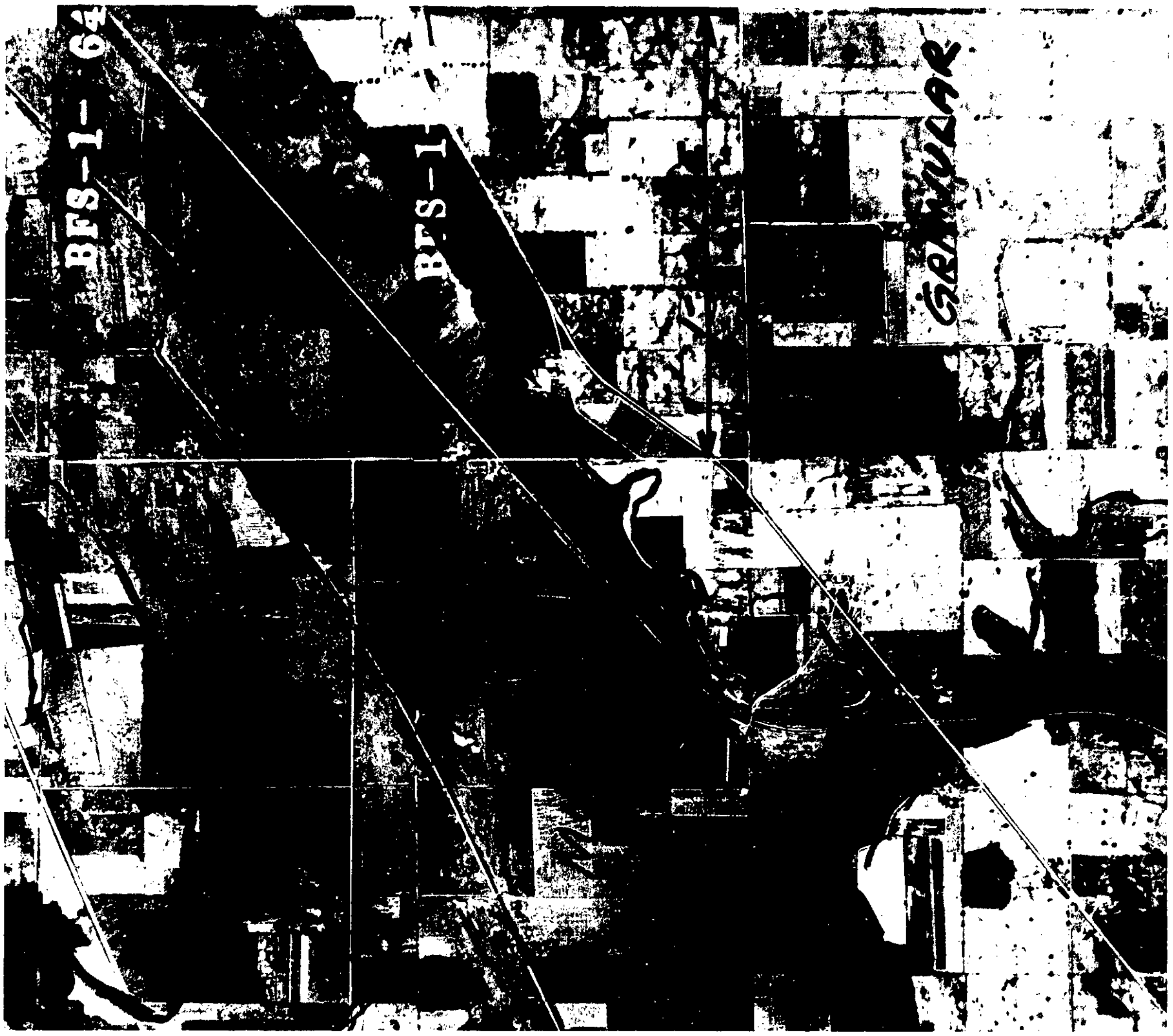


FIGURE 14.—*Muck and Gravel.* This pattern is frequently encountered on photos of areas covering parts of Indiana, Ohio, Michigan, Illinois, and Wisconsin. The light-colored pattern is that of well-drained gravels while the dark pattern is that of peat and muck. Artificial drainage has opened the channel area (muck) for agricultural use. Gravel plains, such as those shown here, are excellent sites for runway locations and for sources of granular materials.

FIGURE 15.—*Glacial Lake Beaches.* This northern Michigan airphoto shows the pattern of two distinct glacial lake beaches now occupying the topographic position of terraces. Note the erosional features accompanying each change in slope. The beaches in this instance are granular. See figure 16 for a ground view of a similar situation occurring near Duluth, Minn.

FIGURE 16.—*Soil Texture in a Beach Ridge.* This is a close-up view in a gravel pit showing the texture of a granular beach occurring several hundred feet above the lake at Duluth. Note the horizontal stratification—an indicator of water-deposited material.

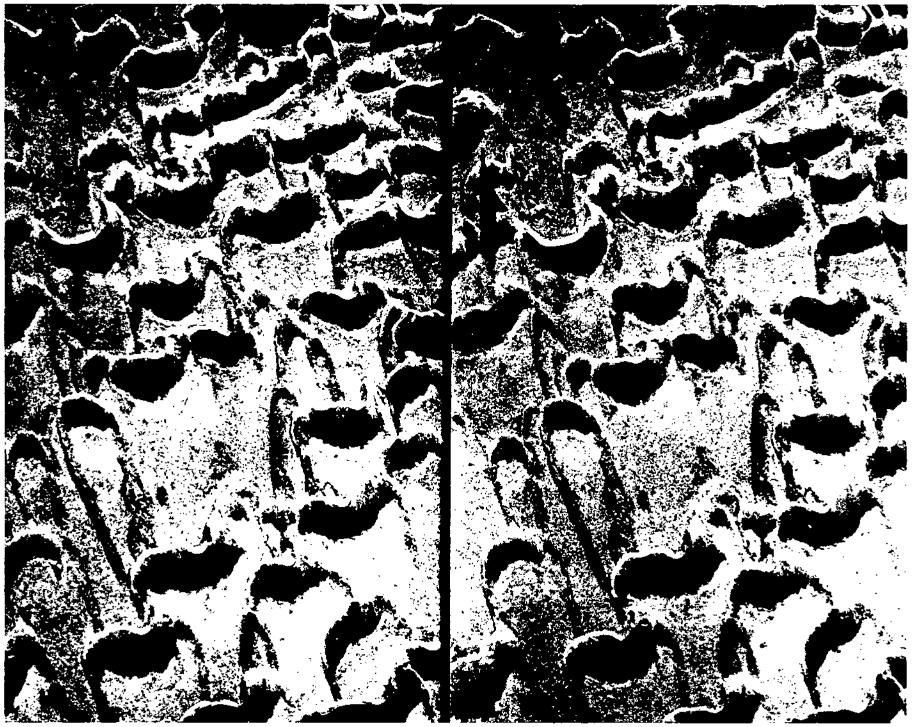

FIGURE 17.—*Barchane Dunes.* A stereopair showing volcanic sand in the form of dunes in central Washington—another variation in the sand dune pattern. This is a region of low rainfall.

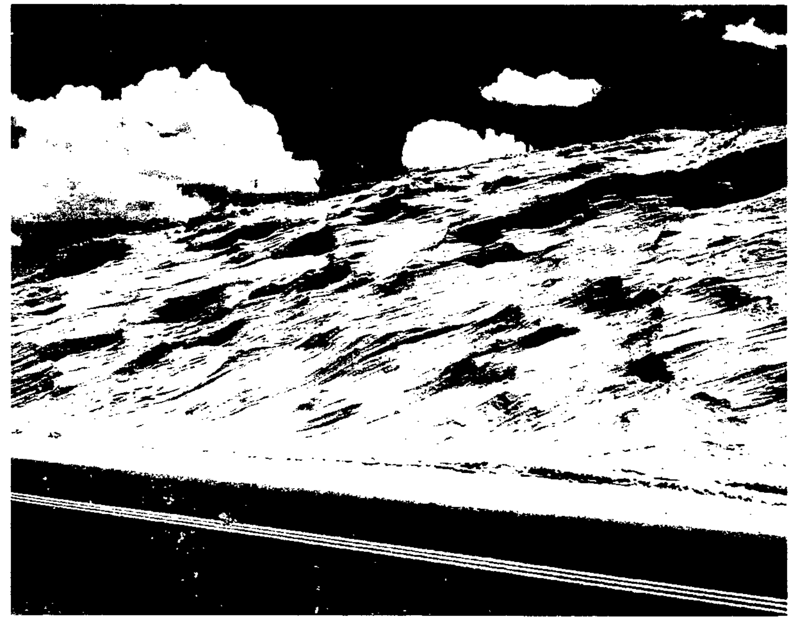

FIGURE 18.—*Ripple and Bedding Marks in a Dune in Utah* (Great Salt Lake).

FIGURE 19. *Sand Dunes in the Great Salt Lake Desert.*

FIGURE 20.—*Sand Dunes in Idaho (arid climate).*

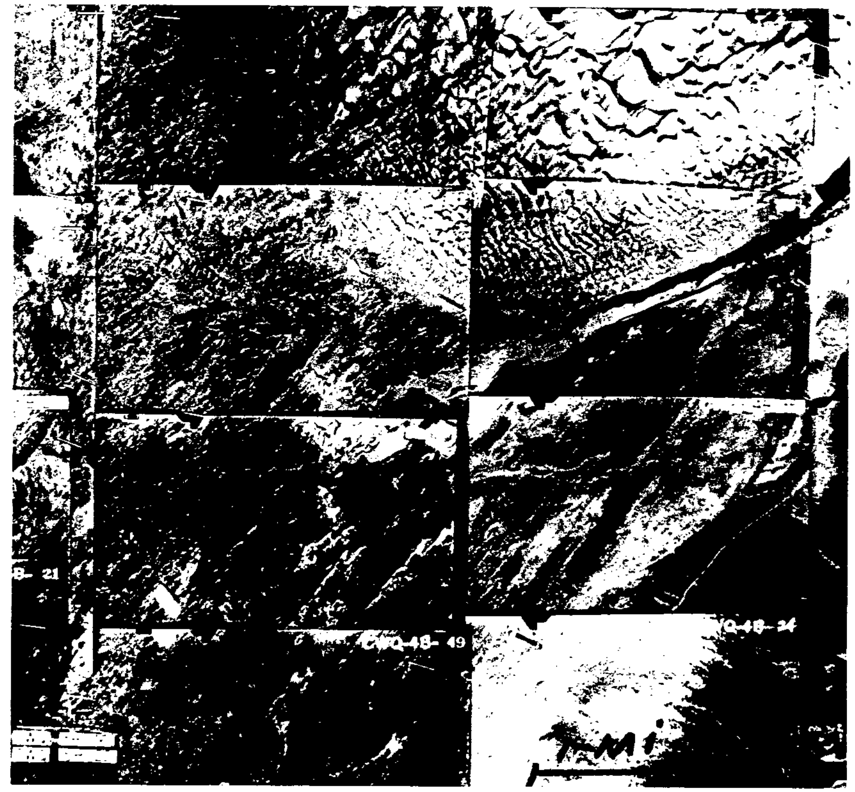

FIGURE 21.—*Rippling Dune Pattern Occurring in Colorado.* Note the directional trend in the streaks below the dune pattern. The entire area has a wind-swept appearance.

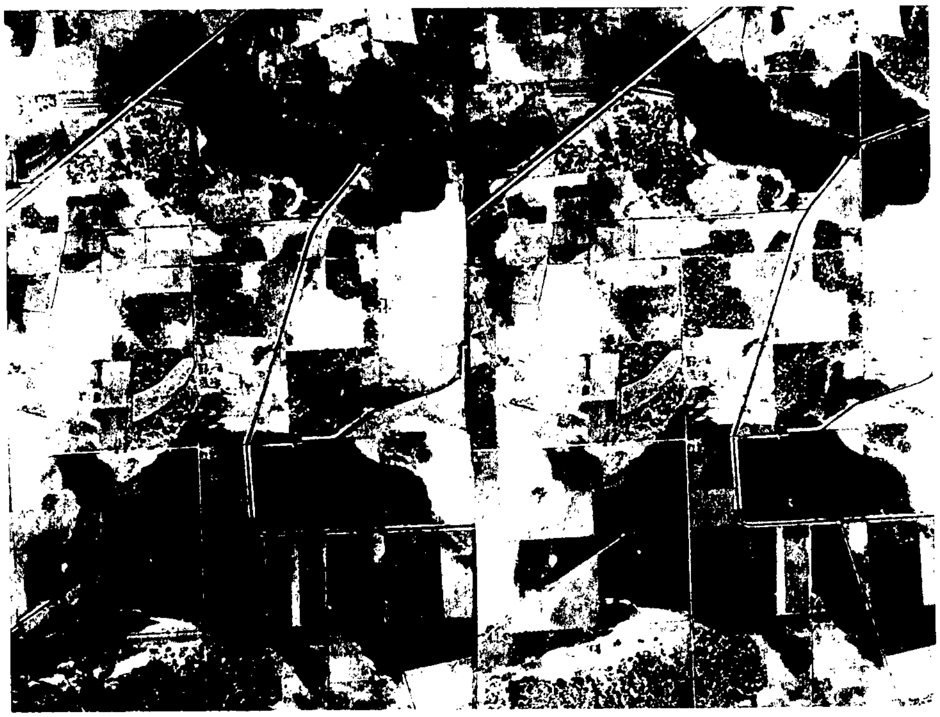

FIGURE 22.—*Muck and Sand Dunes.* This Pulaski County, Ind., stereo-pair demonstrates the reliability of elements of color tone and land form. The white to light gray tones, in this humid area, indicate a well-drained material. Dark gray to black tones indicate high ground-water conditions. The black tones represent shallow muck on sand. The crescent shape of the light areas indicates wind influence which places the material in the sand size. Note natural vegetative differences between the dune sand and other soil areas.

FIGURE 23. *Softly Rounded Hills Typical of the Rolling Areas in the Palouse Silt Region.*

FIGURE 24. *Undulating Topography Typical of the Great Plains Loess Deposits of Western Nebraska.* The low, elongated parallel hills characteristic of loess in this region are not as apparent in this ground photo as they are in airphotos, nor are they as apparent to an observer on the ground as to one in the air.

FIGURE 25. *Gently Rolling Topography of the Relatively Deep Loess of a Major Stream Valley.* Compare the topography of this Southwestern Indiana silt area with that shown in figure 23 representing loess in Washington.

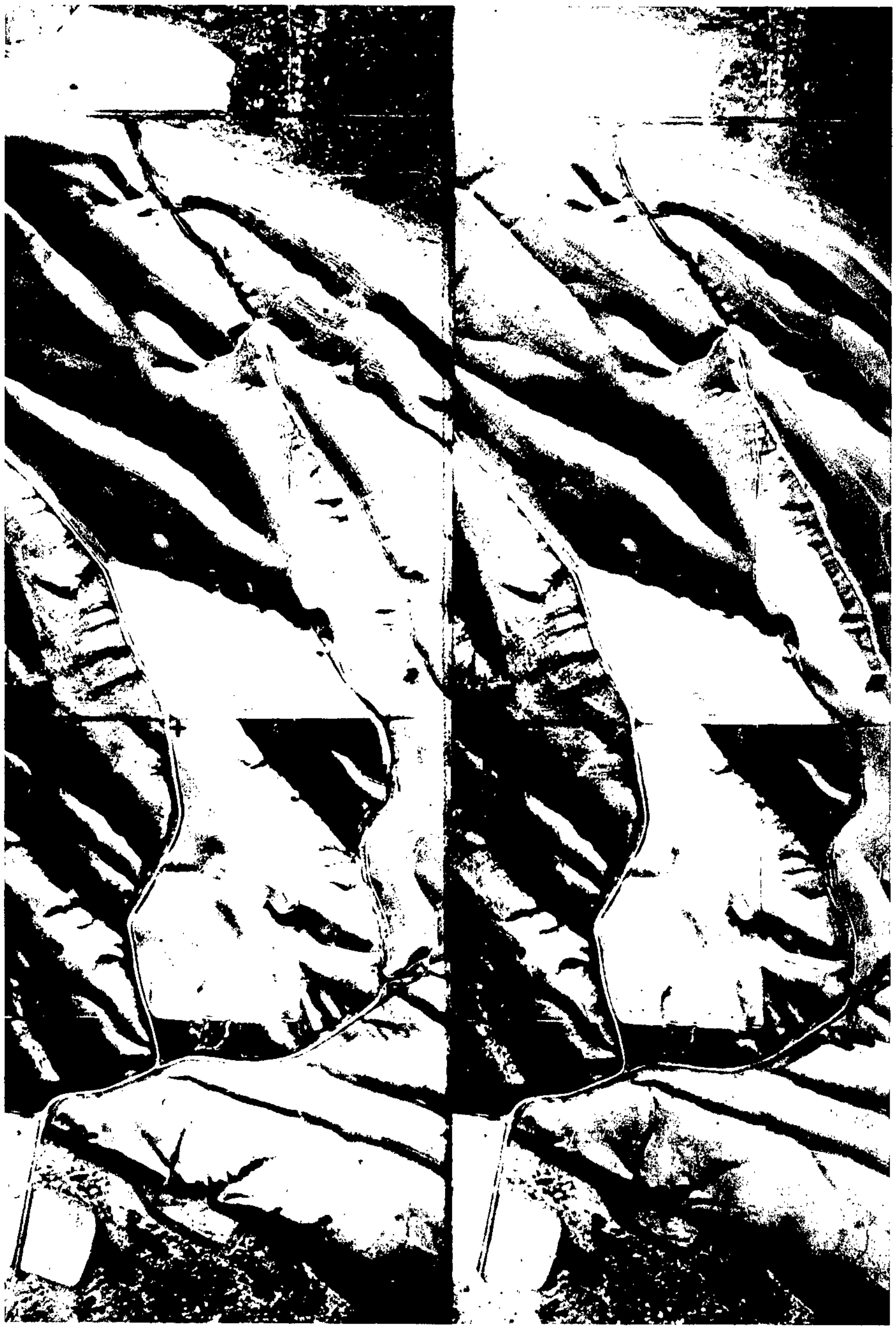

FIGURE 26. *Stereopair of One Type of Palouse Loess, Showing Land Form, Drainage Pattern, Gully Systems, and Land Use Typical of the Rolling Palouse Areas (Adams County, Wash.).* Note that the land form is quite rolling yet the hills are very softly rounded never angular. The drainage of the area consists of a system of parallel gullies, the laterals of which are short and enter at right angles, thereby creating the "fishbone," or pinnate, drainage pattern. Such elements as "cat steps" and pinnacles are not contained in this view because gully erosion has been checked by proper agricultural practices.

FIGURE 27.—*Land Form Characteristic of the More Rolling Areas of the Palouse Silt Region.* The "fishbone" type drainage is present but not apparent because in this area such patterns are more clearly seen from study of mosaics rather than individual prints. Note the softly rounded hill shapes. Erosion is held in check somewhat by proper agricultural practices. However, the gullies that do develop, even though softened, tend to show silt influence.

FIGURE 28.—*Topography Characteristic of the More Level to Gently Rolling Palouse Areas.*

FIGURE 29.—*Great Plains Loess.* Stereopair showing the land form of the level portion of the loess-covered Great Plains in Buffalo County, Nebr. Note the near-absence of pattern features. The land form is suggested by the very faint streaking in the color pattern extending diagonally across the area.

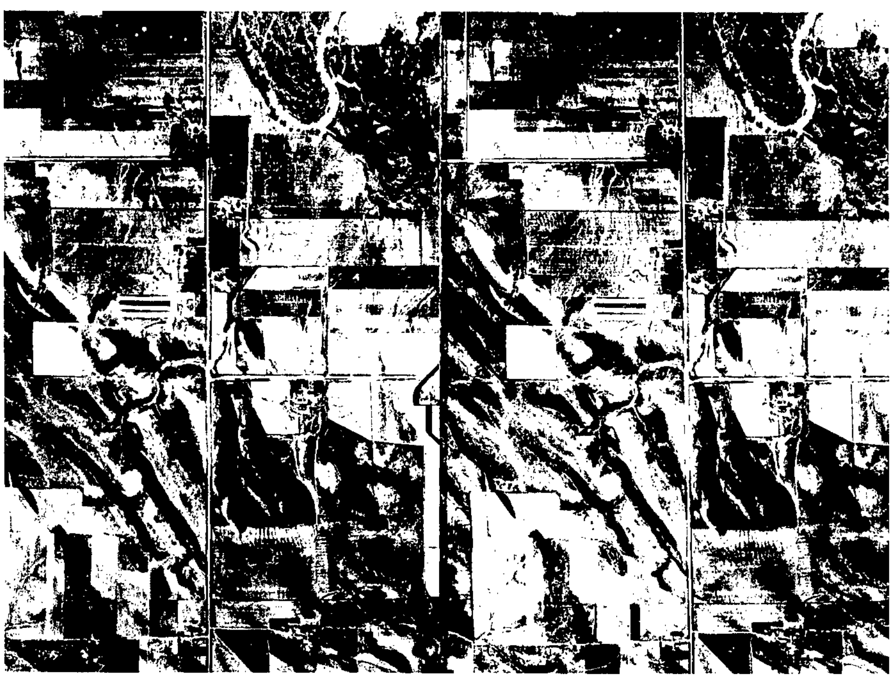

FIGURE 30.—*Loess of the Rolling Areas of the Great Plains.* Stereopair showing the land form of the more rolling areas of the Great Plains loess regions and the strong parallelism of the hills and drainage systems (Madison County, Nebr.).

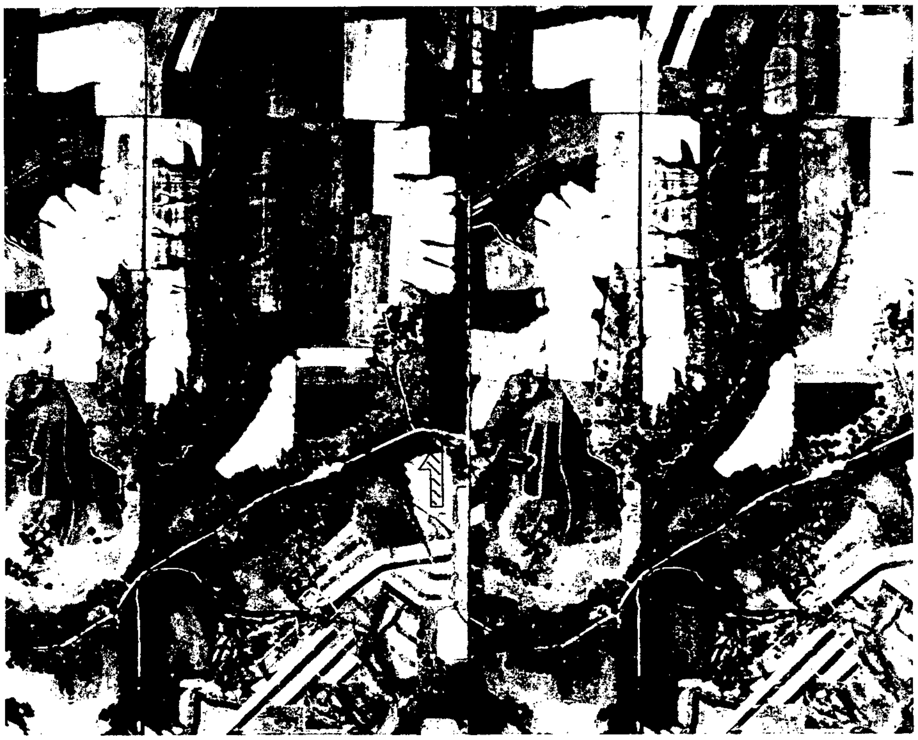

FIGURE 31. *Land Form Typical of the Upper Mississippi River Loess (Jo Daviess County, Ill.).*

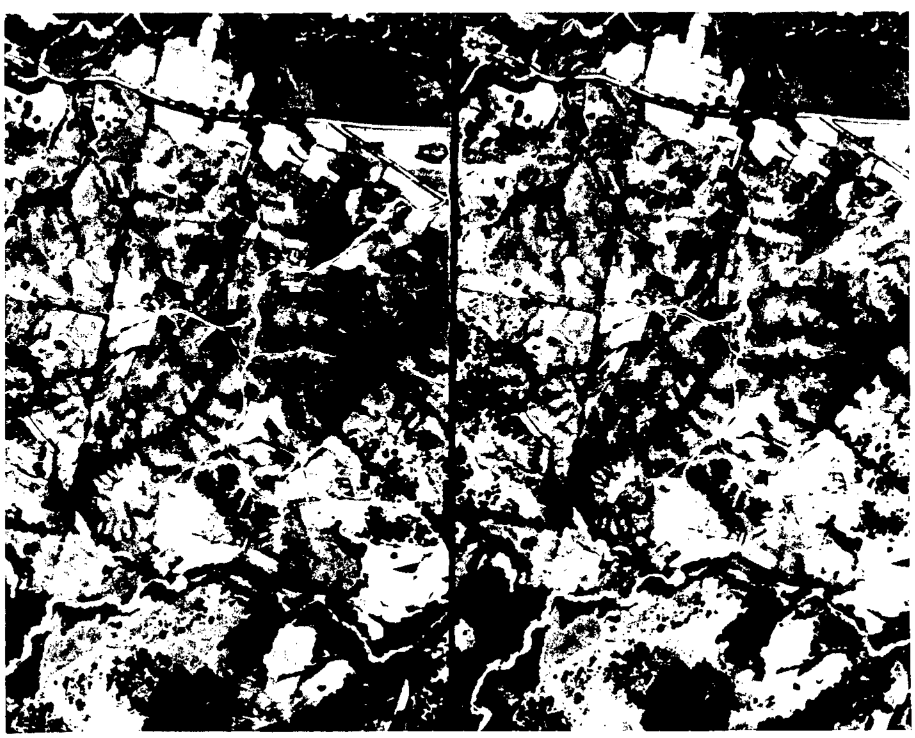

FIGURE 32. *Land Form of the Lower Mississippi River Valley Loess Area (Adams County, Miss.).*

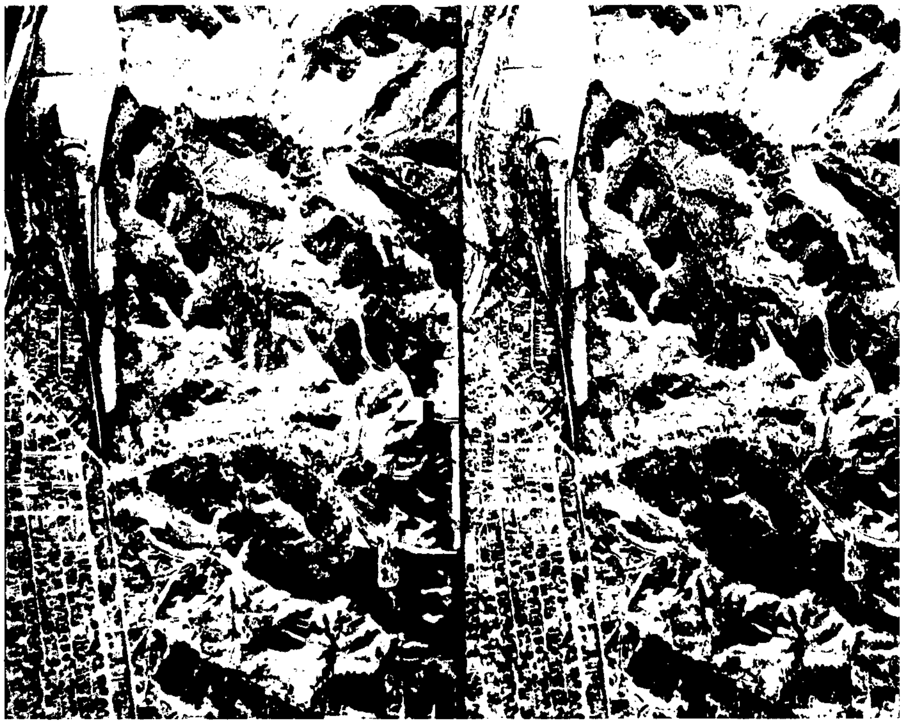

FIGURE 33. —*Rugged Loess Topography Adjacent to the Missouri River in Woodbury County, Iowa.*

FIGURE 34. —*Rolling Land Form in the Missouri Valley Some Distance from the River.* Note the existing parallelism in hills and drainage systems (Plymouth County, Iowa).

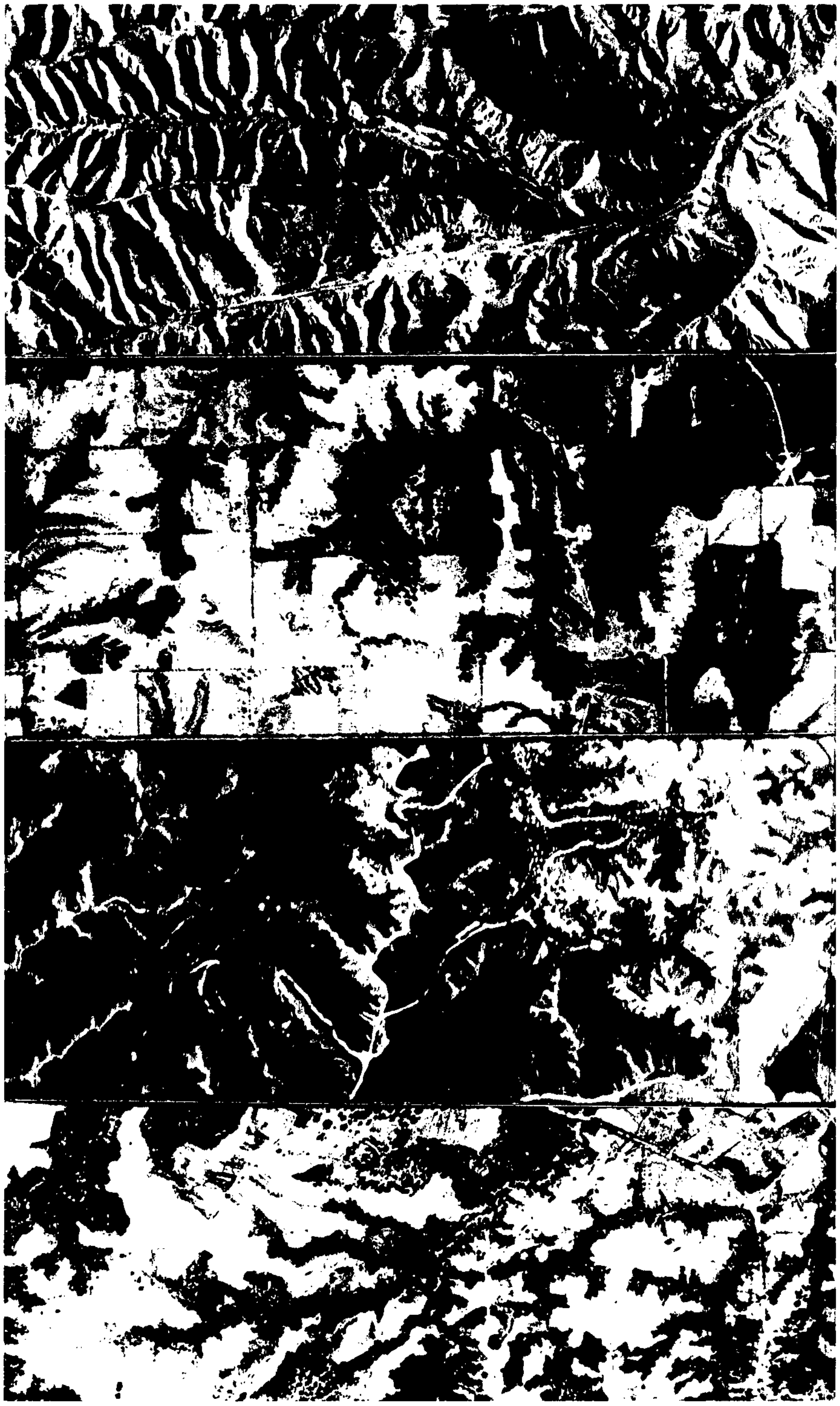

FIGURE 35.—*Loess Patterns.* The uniformity of gully pattern regardless of climate or location is one of the outstanding features of loess. These four areas represent the loess of Nebraska, Indiana, Mississippi, and Iowa. The loess gully arrangement is "fishbone" in shape with a long backbone channel and short right-angle tributaries. That loess is a droughty soil in subhumid to humid climates is indicated by heavy vegetable cover in the gullies of these Indiana, Mississippi, and Iowa patterns.

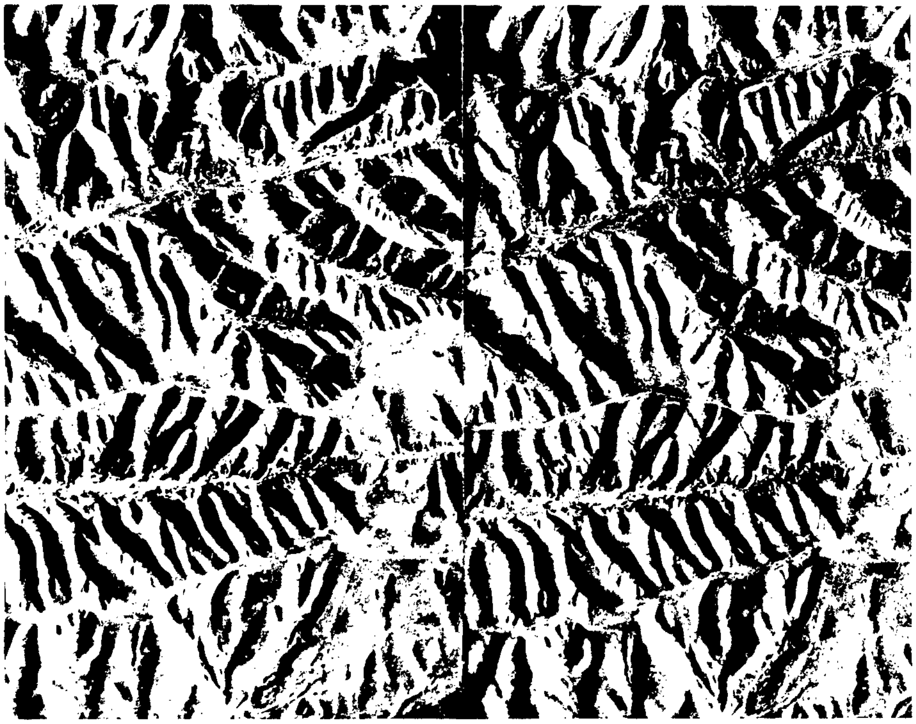

FIGURE 36.—*Loessial Erosion.* Stereopair showing silt pinnacles and the fishbone (pinnate) drainage system. The pinnacles occur as isolated columns in the bottom of gullies or as fins or ribs on gully sides.

FIGURE 37.—*"Cat Steps"*. This is one of the more difficult elements to observe because of the minute detail involved in their photographic reproduction. These appear as minute contours on the slopes.

FIGURE 38. —*"Cat Steps"*. This stereopair illustrates one element of the loess pattern showing how silt tends to maintain vertical slopes (western Nebraska).

FIGURE 39.—*Silt pinnacles*. This eastern Washington stereopair illustrates the formation of another identifying element of the loess pattern. Note the vertical gully faces, the pinnacle forms, and the loess ridge in the background.

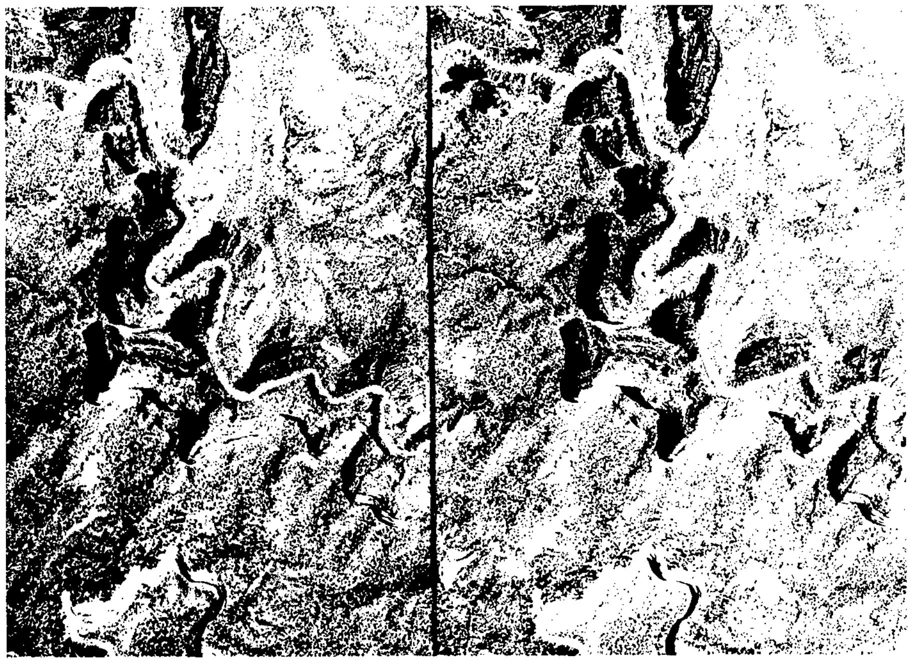

FIGURE 40. *Massive Sandstone*. This shows the blocky land form produced by weathering of thick beds of flat-lying sandstone in an arid region. The outstanding features of this pattern are the deep canyons, intermediate plateaus, and high mesas (Mesa County, Colo.).

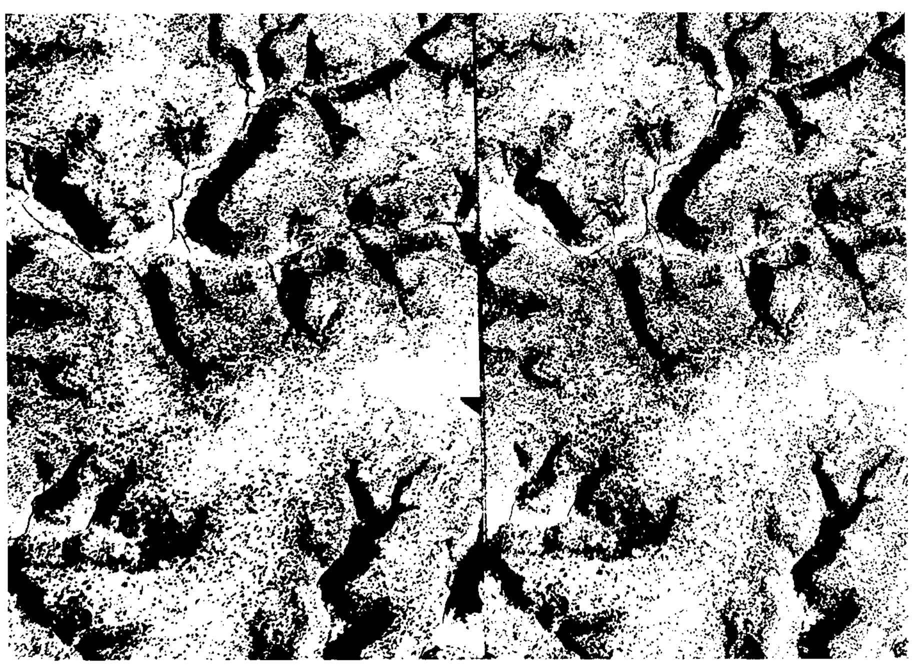

FIGURE 41. *Thick Sandstone on Shale*. This shows nearly horizontal-lying strata of sandstone on clay shale. Note that the sandstone layers (inter-drainage divides) produce vertical slopes and that the clay shale layers weather to produce soft slopes (Otero County, Colo.).

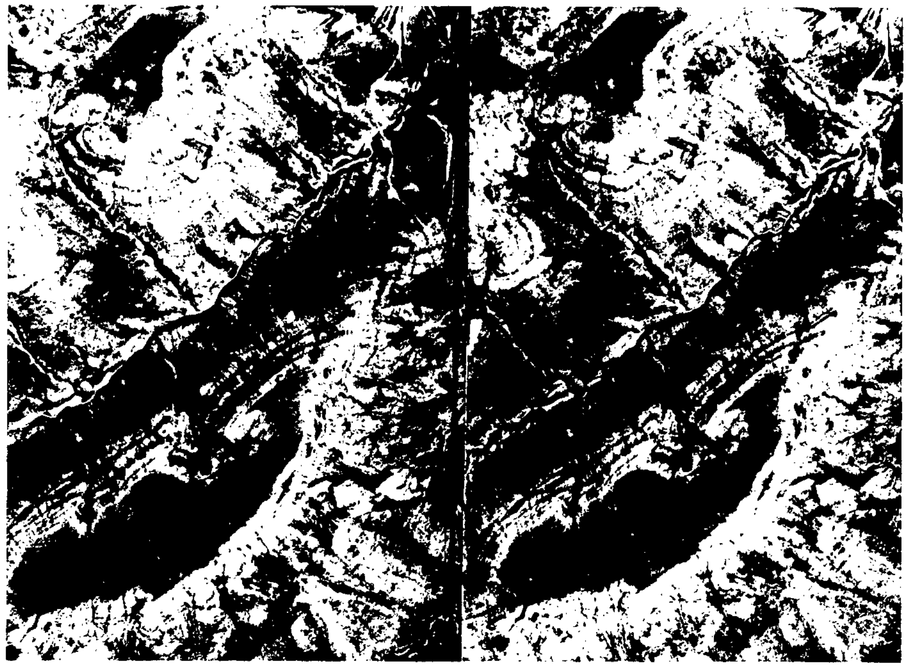

FIGURE 42.—*Badlands Formed in Nearly Horizontal Beds of Variegated Clay and Sandy Shales (10 to 15 inches of rainfall).* Note the flat-topped portion which is a remnant of the once level plain. The softly rounded gully slopes and erosional scars are characteristic of the clay shales. The over-all drainage pattern of this area is dendritic (Sheridan County, Wyo.).

FIGURE 43.—*Tilted Sandstone and Shale.* This shows tilted, thick shale capped with alternating layers of thinly bedded sandstone and shale (15 to 20 inches of rainfall). The drainage pattern is trellis-like (Fremont County, Wyo.).

FIGURE 44.—*Tilted Sandstone and Shale*. This shows tilted, thick shale found in a region of 35 to 40 inches of rainfall. Compare the drainage pattern and the soft slopes in this figure with that in figure 43.

FIGURE 45.—*Tilted Sandstone and Shale*. This photo shows tilted, thick shale strata capped with sandstone in a region of 10 to 15 inches of rainfall (Mesa County, Colo.).

FIGURE 46.—*Badlands near Sidney, Mont*. This is a stereotriplet. The badlands were caused by active erosion in shales that have a relative thin mantle of glacial drift. Several erosional features and land forms are contained in this area. The main land forms and erosional features are indicated on the airphotos as follows: *A*—dissected remnant of the original flat upland plain; *B*—earlier, more stable erosion (geologic) of a previous erosional cycle; *C*—dissected terrace or alluival fan of material brought from *B; D*—small, recent alluvial fan from area *B; E*—most recent and most active erosion in the area; *F*—alluvial fan composed of material derived from *E;* and *G*—recent alluvium of the Yellowstone River.

The original land form, which is still preserved in places, now occupies the position of a dissected plain consisting of shallow glacial drift on nearly horizontal beds of sandy and clay shales. The most extensive remnant of this land form has been labeled "A" in the above photo. The gullying on "A" consists of two types: 1—that occurring in the upper portion of the structure, chiefly in glacial drift and; 2—the active erosion that occurs on steeper slopes which cuts through the various shale layers. The relatively inactive gullies in the upland plains have dark centers, appear to be grass-lined, have broad V-shapes; have rounded upper slopes, and extend many thousand feet into the upland plain before becoming active due to gradient change. The active gullies expose the various layers of hard and soft shales and each change in material results in changes in gully slopes and shapes.

The areas labeled "B" have been reduced by a previous erosional cycle and have become more stable in erosional activity. The gully systems are long and extend 2 or more miles headward. That the activity of erosion has been somewhat retarded is indicated by the presence of considerable colluvial material which has reduced the angularity of some of the valleys. Furthermore, the changes in slope between dissimilar strata have been softened by such deposits. The gradient of each of the main channels is relatively low (as compared to the system in "E") which probably may account for some of the retarding action. Recent erosion in the "B" gully system has been in the form of lowering of the flat-bottomed channels. Earlier erosion of areas such as "B" has contributed largely to the formation of a large alluvial fan, or terrace (outlined by a series of broken lines). This land form has been covered in places by other and smaller fans.

The area labeled "C" consists of a terrace remnant that appears to be covered in part by material eroded from the uplands and in part by stream deposits of the Yellowstone River at a time when this stream was more active than at present. The topsoil appears to have a high silt content while the general terrace texture appears to be relatively impervious.

The area labeled "D" is a small alluvial fan consisting of the most recent deposits of material eroded from gully system "B". The material of this fan is chiefly silt which is shown by the light color which outlines the fan-shaped land form.

The most recent erosional features of the area, and perhaps the most active, is that labeled "E". Detailed stereoscopic examination of the photos shows headward erosion to be severe. The general gradient is steep, and the gullies lateral to the main channel are steep and V-shaped. Changes in material due to the cutting through of strata of varying resistivity result in changes in gully shapes and slopes. This is evident at several places throughout this system. The material being eroded from "E" is being deposited in the form of an alluvial fan at "F".

The recent alluvium of the Yellowstone River, which is silty in texture, had been labeled "G" in the airphotos. Several current scars and ridges are seen in this area. The ground view contained in figure 47 was taken at location 1 with the arrow indicating the direction of photography


FIGURE 46.—(See explanatory text on opposite page.)

FIGURE 47.—*Badlands*. View of badlands taken from location 1 in figure 46 near Sidney, Mont., formed by erosion of shales (Fort Union and Tongue River).

FIGURE 48.—*Badlands*. Stereopair of badland topography characteristic of the upland area away from the major stream valley. The level plateau illustrates the remnants of a former plain. Also note the soft-rounded slopes of the clay-shale members of this formation (Fort Union).

FIGURE 49. *Badlands Formed by Erosion in Shale (Lebo) near Glendive, Mont.* Very little of the original upland plain surface is left. Most of the area has been reduced by erosion forming colorful badlands. Figures 50 and 51 illustrate topography of this land form, and figure 52 illustrates performance of flexible pavements built on this shale. The chief structure at this location is clay shale which weathers to produce soft-rounded land forms. Thin layers of sandy shales and weak sandstone tend to preserve the hills, producing a more rugged topographic appearance.


FIGURE 50. *Softly Rounded Clay Shale Features.* This is a stereophoto of shale (Lebo) badlands taken at location 1 in figure 49. Note the light color and soft-rounded slopes of the clay-shale member (*C* near the fence) and compare with the more angular shape of the sandy shale and thin sandstone member (*S*—upper portion of picture).

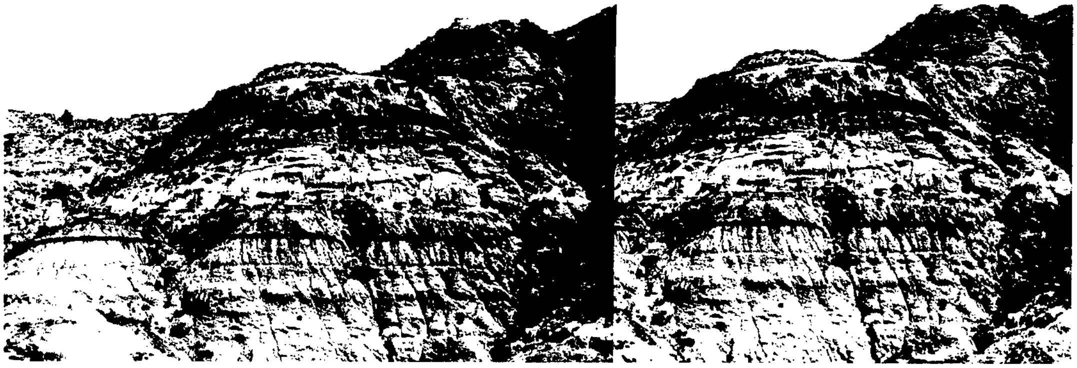

FIGURE 51.—*Broken Land Form of Shale with Sandstone.* This stereopair was taken at location 2 in figure 49 and shows a detailed view of sandy and clay shales and associated weathering of the shale member (Lebo). Note the many changes in shape and slope as layers of varying resistivity are crossed by erosional scars This causes a broken land form.

FIGURE 52.—*Highway Cut in Shale.* The numerous patches in the flexible pavement illustrate the engineering characteristics of this material. (See location 3 in fig. 49.)

FIGURE 53.—*Shale Topography.* This stereopair illustrates destructive forces (erosion of the shale), transportation and deposition (alluvial fan building), and recent destructive action (erosion of the fan). This is west of Miles City, Mont.

FIGURE 54.—*Escarpment Produced by Sandstone (Hell Creek) on Shale (Bearpaw) west of Forsythe, Mont.* The softly rounded slopes occur on the clay-shale member.

FIGURE 55.—*Coniferous Trees on a Sandstone Outcrop.* The remainder of the area is shale. The picture was taken on U S 87 north of Billings.

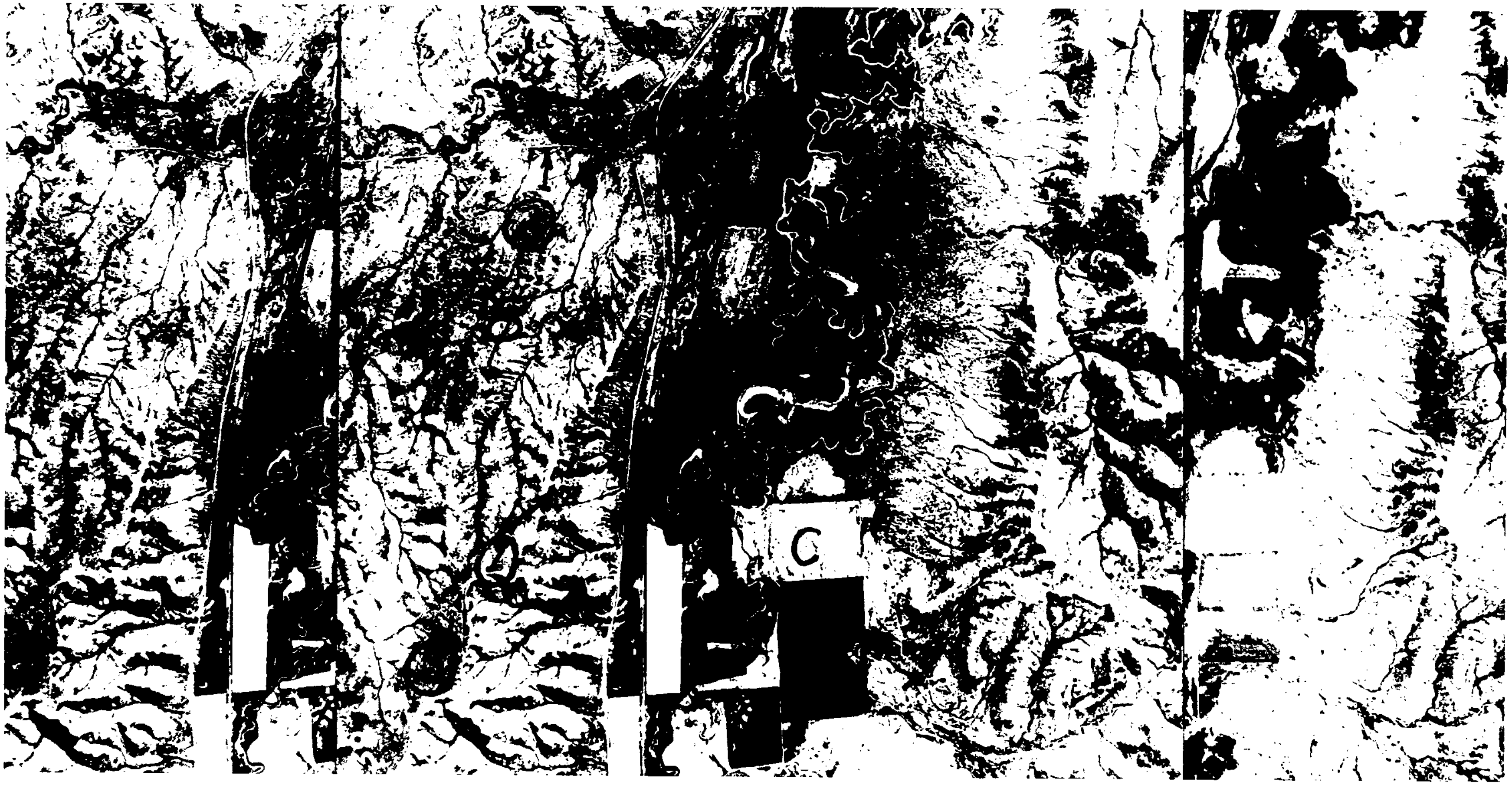



FIGURE 56.—*Shale Valley*. This is a stereotriplet of a stream valley in shale (Colorado) near Grass Range, Mont. Detailed study of these photos makes it possible to locate different types of shales and to observe their influence on drainage and erosion. Area A contains that erosion and gullying that crosses the various strata forming the valley wall. Note the change in slope produced by the sandy shale members which supports a heavy vegetative cover near the top. This is underlain by the impervious clay shale which probably acts as a barrier to underground water, thus allowing the sandy shale to become a water-bearing strata. The drainage and erosion on area B, the dissected upland portion of the area, is semi-trellis in form with parallel gullies flowing on top of the various strata. Note that a few remnants of the sandy shale which are light in color and are accompanied by slope changes occur frequently in this upland area. The arrows at locations 1 and 2 show the direction of photography contained in figures 57 and 58. Location 3 is a cultivated remnant of the once level upland. The upland in this area contains a mantle of Tertiary gravels. Area C is the alluvium—somewhat gravelly—of the major stream.

FIGURE 57. *View Looking Across the Valley in Shale.* The sharp change in slope of the sandy shale members which support the vegetation is clearly shown in this ground view and can also be seen by close observation of location 1 in figure 56. The vegetation of the opposite side of the valley and the flat horizon of the opposite upland suggests the existence of a former peneplane.

FIGURE 58. *Clay-Shale Erosion.* Note the light outcrops or remnants of a clay-shale member of this shale area. The view was taken at location 2 in figure 56. The soft slopes identify the light outcrop as consisting chiefly of clay shale. Detailed study of slopes in areas 1 and 2 in figure 56 will show clearly the difference between the clay and sandy shale.

FIGURE 59.—*Granitic Intrusion Fringed by Upturned Strata of Sandstone and Shale.* The vegetation is confined chiefly to the sandstone layers.

FIGURE 60.—*Upturned Sandstone Ledges.* This ground view was taken at location 1 in figure 59 and shows the upturned sandstone ledges which fringe the granitic intrusion.

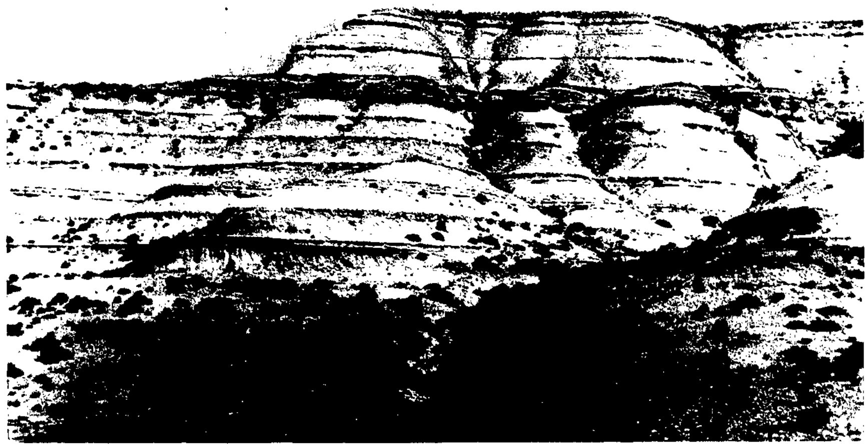

FIGURE 61.—*Badlands in Shale* (*Green River formation*) *east of Green River, Wyo.* The thin, harder, layers separated by gently sloping softer layers would present a contoured appearance in the airphoto pattern.

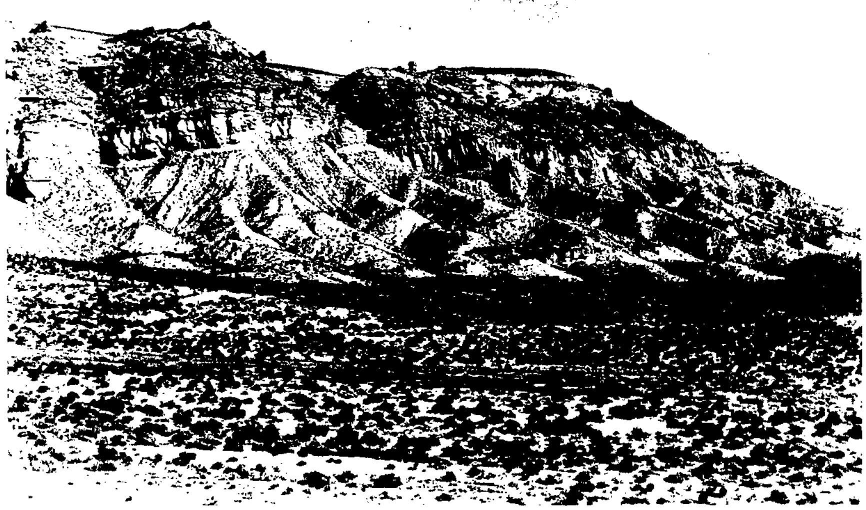

FIGURE 62.—*Shale* (*Cody*) *Capped with Sandstone and Shale* (*Mesa Verde*). This is 6 miles east of Rock Springs, Wyo. Note the difference in the erosion on sandstone and on the shale. This difference is one of the outstanding features used to separate the two types of rock when viewed in matched pairs of airphotos.

FIGURE 63.—*View of Erosion in Shale (Permian and Pennsylvanian), west of Rawlins, Wyo.*

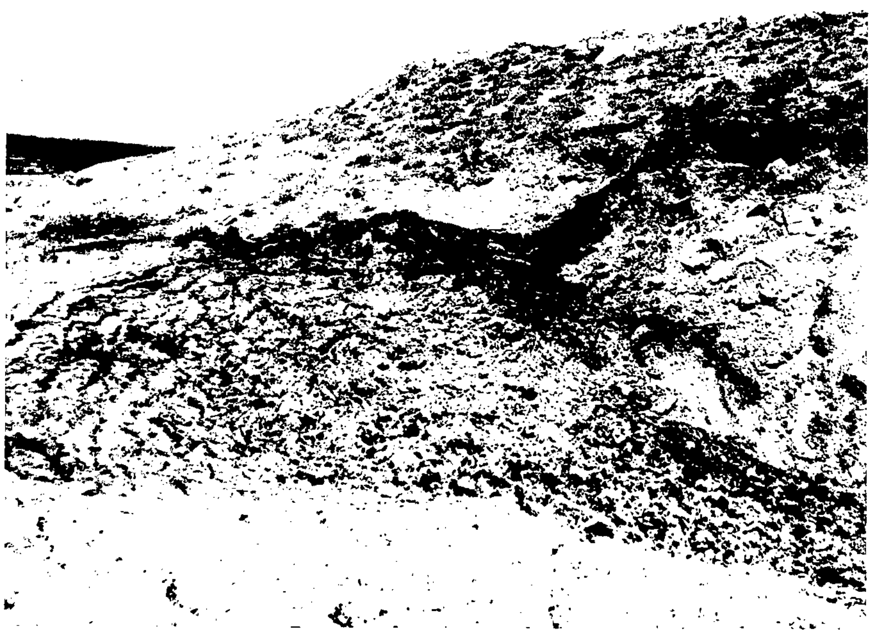

FIGURE 64.—*Scoria in the Making, near Hanna, Wyo. (Mesa Verde formation), from the Burning Lignite Beds.* Here the soil has settled where underlying lignite beds have been burned.

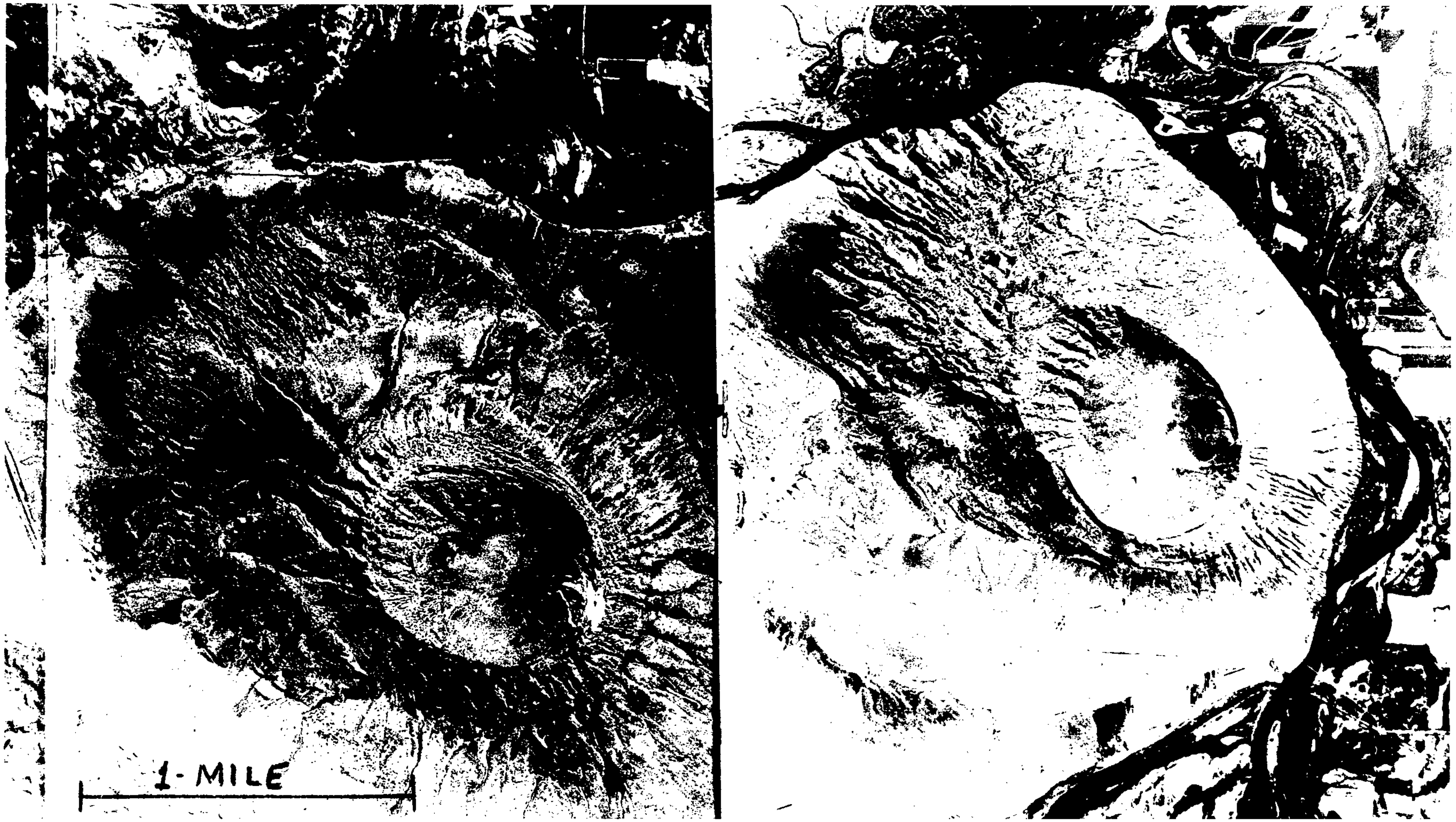


FIGURE 65.—*Volcanic Cinder Cones.* This Jefferson County, Idaho, photo depicts two cinder cones built up of volcanic ash and breccia. Note the radial drainage pattern. This is on the edge of a basalt plateau consisting of an older flow material. The large size of the craters is indicated by the mile scale.

FIGURE 66.—*Stereophoto of Volcanic Cones.* This Shasta County, Calif. area contains three distinct volcanic cinder cones. Note the box-shape of the erosional features of the older lava flow at the base of the large cone.

FIGURE 67.—*Stereophoto of a Large Volcanic Cone.* Note the changes which occur in color, vegetation, slope, and in gully characteristics about half-way up the slope of the cone. The dark rocks are remnants of an earlier flow.

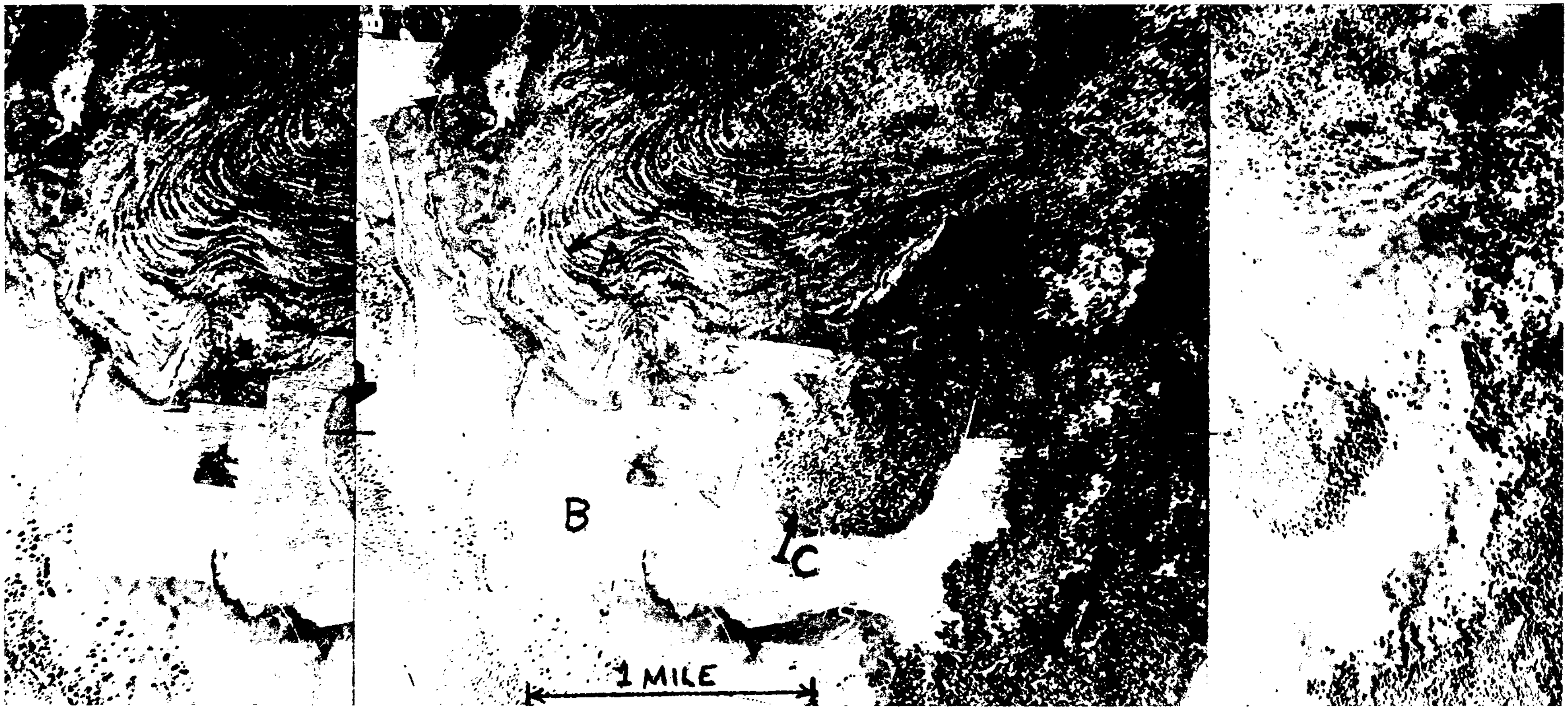


FIGURE 68.—*Stereotriplet of a Lava Flow*. This Shasta County, Calif., area contains: *A*, the most recent lava flow; *B*, an older flow covered with pumice and volcanic breccia; *C*, an old crater or volcanic channel. The most recent flow has not weathered sufficiently to produce soil for timber growth.

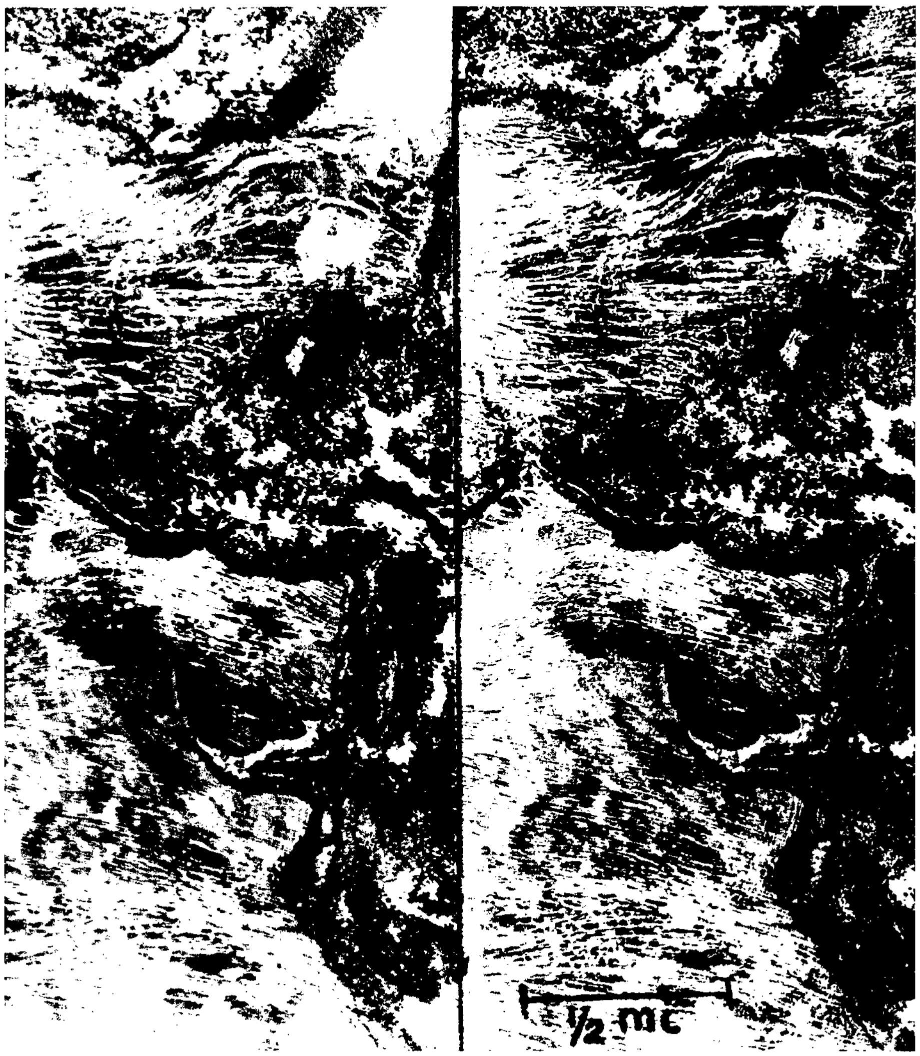


FIGURE 69.—*Stereophoto of a Dissected Basalt Plateau.* This airphoto illustrates one of the many surface features exhibited by basalt flows. Note the streaks or cracks which are contained in the surface. The parallel trend of these may possibly be orientated with the direction of flow of the original deposition. Essentially this area is a high, flat, dissected, barren plateau. Detailed inspection along the vertical faces of the cliff reveals the columnar structure. A change in slope, together with a different pattern of the broad valleys, suggests that the basalt is not very thick and rests on soil of an older period.

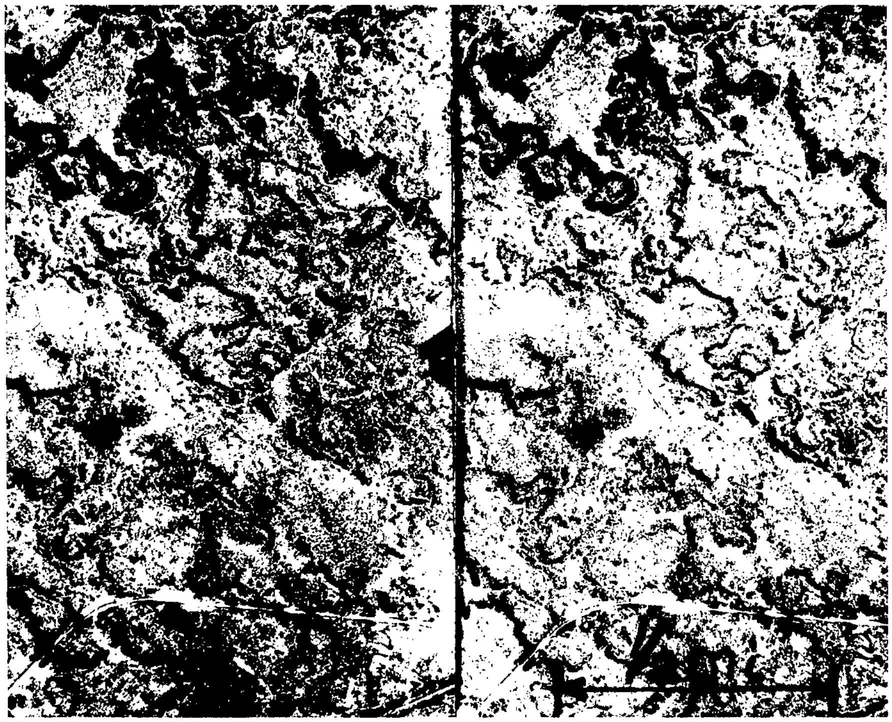

FIGURE 70.—*Highly Dissected Basalt Plateau.* This illustrates one of the erosional features often common to basalt patterns—that of numerous isolated basalt mesas. In this arid region there is very little residual soil development, probably because any soil that develops is removed either by the wind or by flash floods (Jefferson County, Idaho).

FIGURE 71.—*Ground View of a Basalt Mesa.* The manner in which telephone poles are propped up on the mesa illustrates the absence of a residual soil development on the top.


FIGURE 72.—*Stereophoto of a Deep Gorge, or Coulee, in the Columbia River Plateau.* There are three basalt flows represented in this photo. The columnar structure of the basalt is exposed along the coulee sides.

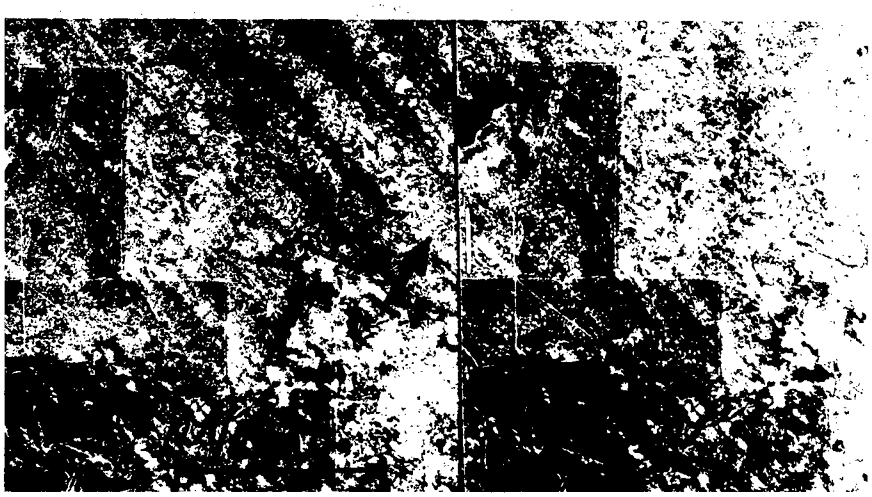

FIGURE 73.—*Stereophoto Showing the Polygon Pattern of Basalt.* The arrows point to clusters of polygons which were formed during the cooling of the hot lava (Jefferson County, Idaho).


FIGURE 74.—*Stereophoto of a Series of Several Basalt Flows Separated by Residual Soil Development (Garfield County, Wash.).* See ground photo in figure 75.

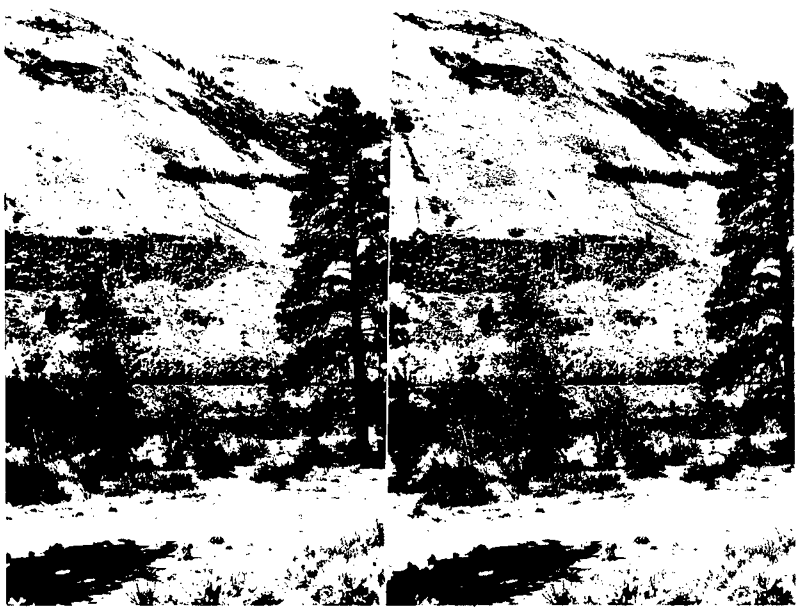

FIGURE 75.—*Ground View of a Series of Basalt Flows in the Columbia River Plateau (Garfield County, Wash.).*


FIGURE 76.—*Airphoto of a Basalt Area Termed as "Scab Lands."* This photo illustrates the following elements: Nearly flat topography, scant vegetation, large channels, polygons, small mounds of gravel, and orientation of vegetation with the shrinkage cracks in the basalt. The area labeled "A" is an old channel (fig. 77). The arrow at "B" indicates the location of figure 78. Area "C" is a covering of loess.

FIGURE 77. *Ground View of a Channel in Basalt (A in fig. 76).* Note the changes in vegetation; there is grass on the upland flats, sage brush occurs on the side slopes and marsh vegetation is supported in the channel.

FIGURE 78. *Ground View of "Scab Lands" in the Basalt Region* (location "B" in fig. 76).

FIGURE 79. *Stereophoto of Thin Layers of Basalt and Thick Layers of Soil Between Basalt Layers (Ellensburg formation).* The rounded slopes are produced by the soil mantle and by the soil between the basalt layers. The basalt can be seen as outcropping beds which give a contoured appearance to the hills (Kittitas County, Wash.)

FIGURE 80.—*Highway Cut in a Layer of Basalt on an Inter-basalt Soil Layer (Washington).*

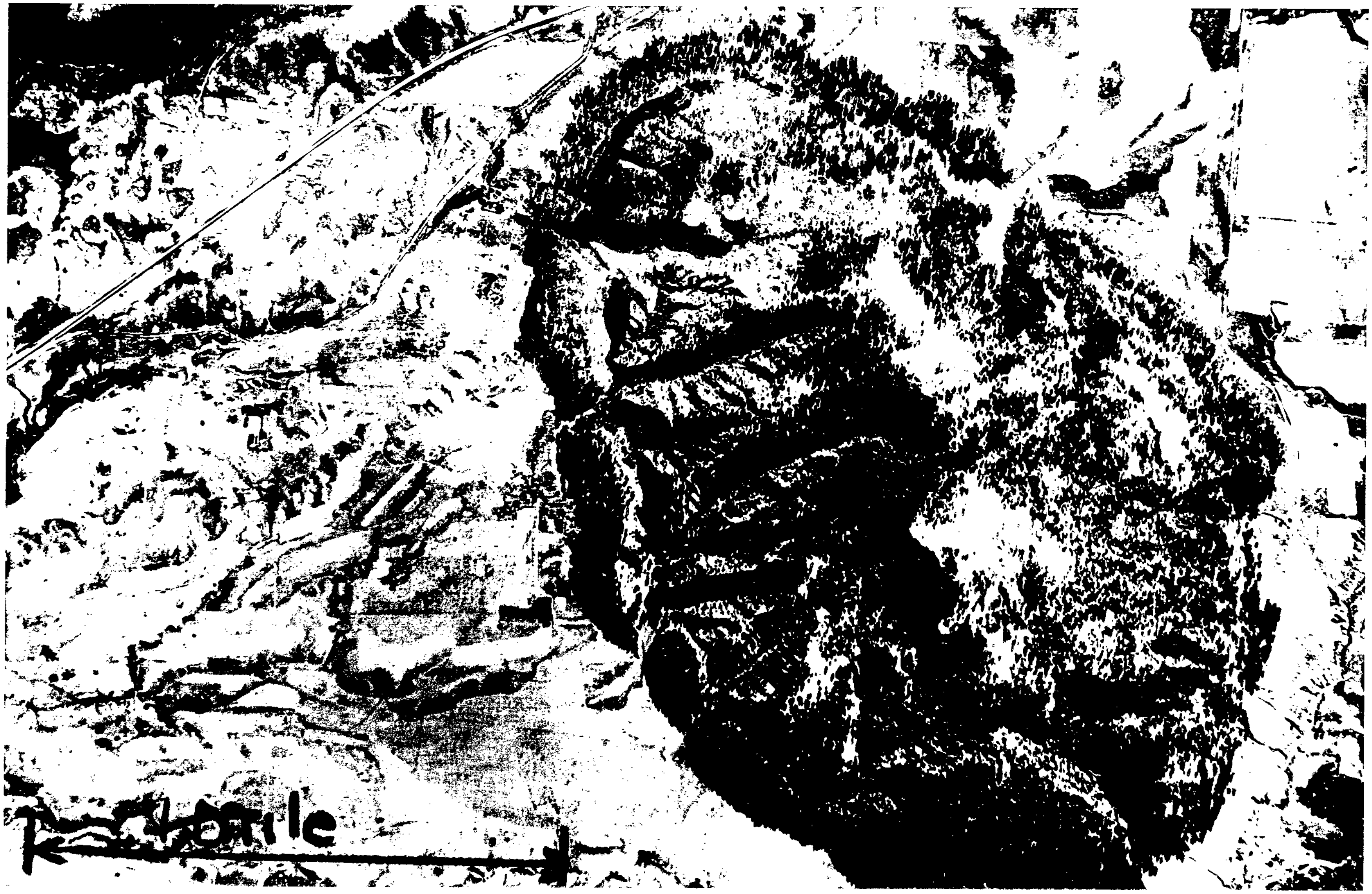


FIGURE 81.— *Airphoto of an Isolated Granite Intrusion in Wyoming.* Overlying sediments have been removed by erosion.

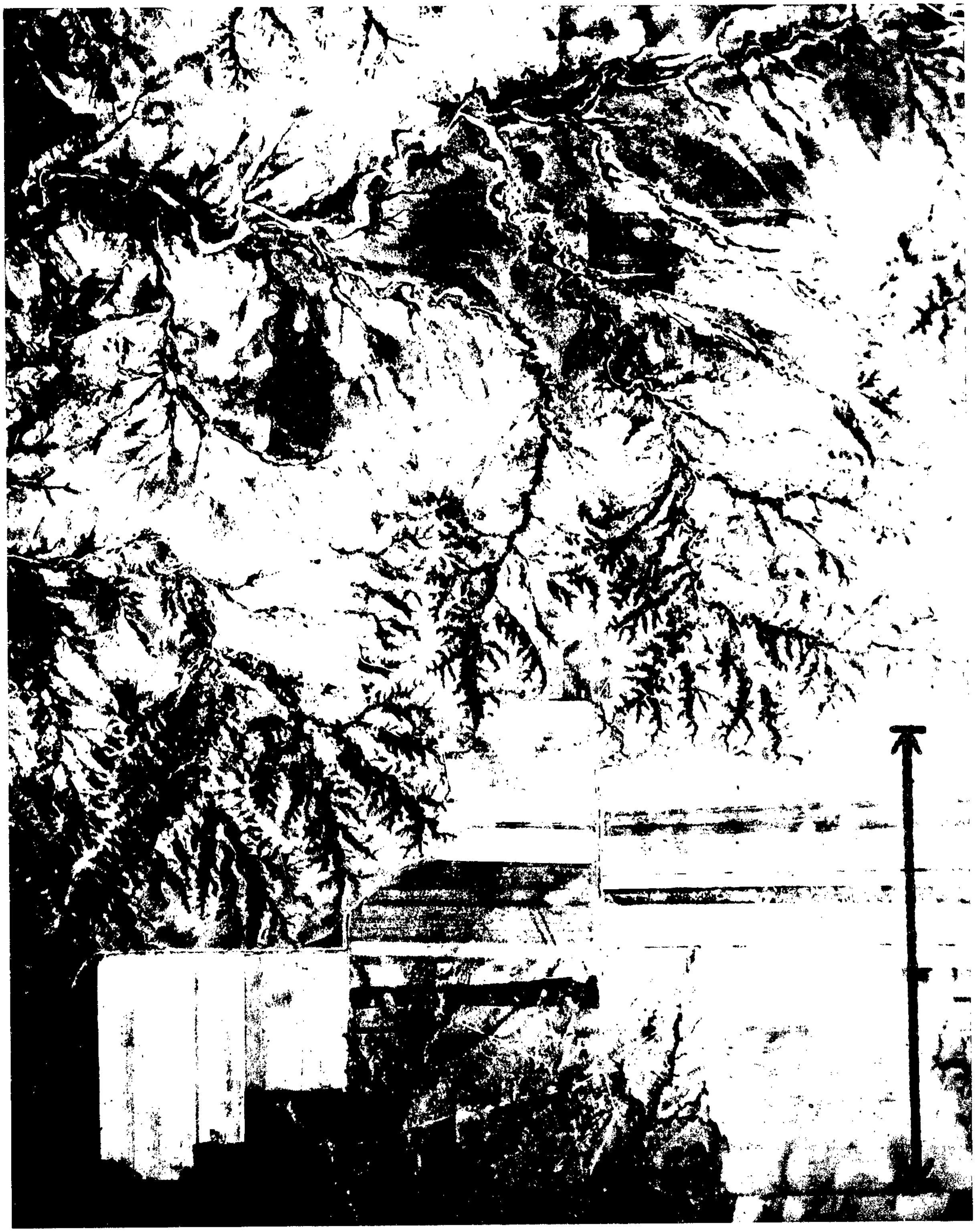

FIGURE 82.—*Airphoto Pattern of Great Plains Granular Outwash Mantle in Montana.* This pattern is representative of the Yellowstone River terraces, Missouri River terraces, and the "Flaxville Gravels" areas.

FIGURE 83.—*Topography Typical of the Yellowstone Terraces in Montana.* This photo illustrates the broad, level, expanse which is characteristic of the vast terraces of such Great Plains streams as the Yellowstone River.

FIGURE 84.—*Badland Formations Along the Yellowstone Terraces.* This photo shows the differences in erosion characteristics between the recent gravel outwash mantle and the underlying shale. Note the change in slope at the gravel-shale contact.

FIGURE 85.—*Gullying in the Granular Outwash Mantle of the Yellowstone Terraces.* This photo shows the V-slopes associated with gullies in the granular terrace materials.


FIGURE 86—*Granular Outwash Mantle Near the Big Snowy, Highwood, and Little Belt Mountains in Montana.* The outwash mantle is granular material washed from these mountains and deposited as a vast fluviatile mantle on shale. Among the more general photo pattern elements which indicate the deposition of this material by water and its granular texture are flat topography; current scars and ridges; light soil color tones; general speckled and mottled pattern; directional or parallel trend in streams, current scars, ridges and erosional features; sharp V-shaped gullies; and steep faces associated with the larger valleys or gullies. Essentially, there are two land forms in this photo: Area *A* is a broad, somewhat braided, recent alluvial valley; and area *B* is the flat-topped remnant of the original fluviatile outwash plain. The entire area is underlain by Colorado shale which is the major bedrock of the region. The presence of the shale may partly account for the characteristics of the broad flat-bottomed valley crossing the area (*A*). The materials of both regions *A* and *B* are granular; however, depressed area *A* contains more fine textured soils intermixed with the gravels than does area *B*. This is shown by the generally darker color tones over the entire valley and in the small braided sections of the valley floor. It is interesting to note that as long as the gully sections are in the granular soils, above the shale, they are V-shaped in section; as soon as the shale is encountered, the section changes to one having steep sides and a flat bottom.

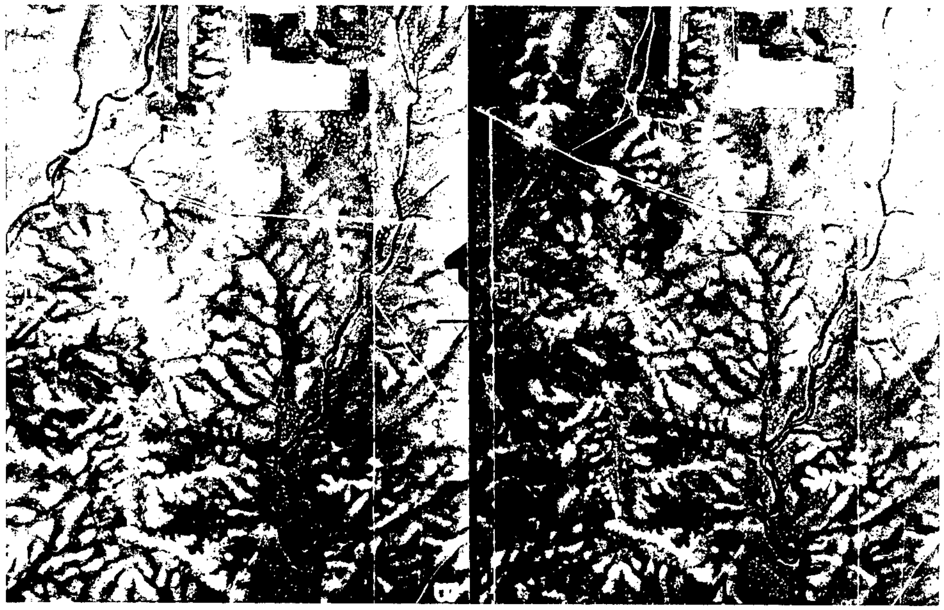

FIGURE 87.—*Stereopair Illustrating a Typical Pattern of the Great Plains Mantle.* This area, near Cheyenne, Wyo., is a dissected plain consisting of flat, gravel-capped mesas. Generally, the texture of the underlying material consists of semiconsolidated sands, gravels, and silts. The underlying material, mapped as Arikaree, is a calcareous sandstone. The flat-topped mesas are outlined by the light-colored rim or contour pattern. The gravel cap on the mesas is indicated by a steep slope associated with the cap, light color tones, a light fringe or outlining band, and small circular infiltration basins. The light outcrop bands on the lower slopes which have less slope than those of the gravels delineate the calcium carbonates which are often called Great Plains marl. At these outcrops a change in slope is evident. The lower surfaces, which perhaps may be thought of as occupying the alluvial position, contain numerous small circular mounds. These are more granular than the surrounding material.

FIGURE 88.—*View of the Gravel-Capped Portion of the Mesa Shown in figure 87.* Note the steep side slope associated with the gravel.

FIGURE 89.—*The Scotts Bluff National Monument in Nebraska* This escarpment exposes several hundred feet of Tertiary deposits which make up portions of the Great Plains structure. The difference in slope between the sandstone (upper) and the shale (lower) is clearly shown.

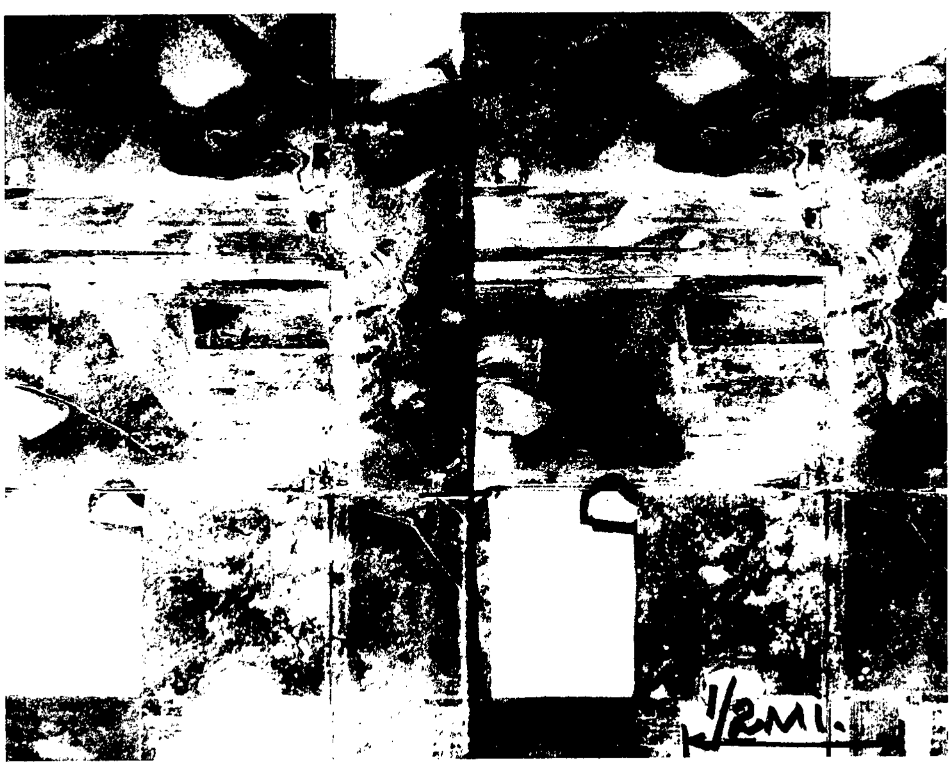


FIGURE 90.—*Airphoto Pattern of a Colorado Great Plains Area Containing Large Circular Basins.* Such a feature is quite common in areas mapped as Ogallala. This area has been wind-swept by fine sands and silts, as indicated by the light-colored streaks.

FIGURE 91. *Great Plains Mantle in Eastern Colorado.* Texturally the area consists of a very shallow deposit of wind-worked sand on partly consolidated sands, silts, and fine gravel, underlain by caliche. The basins are often alkali and covered by the sands.

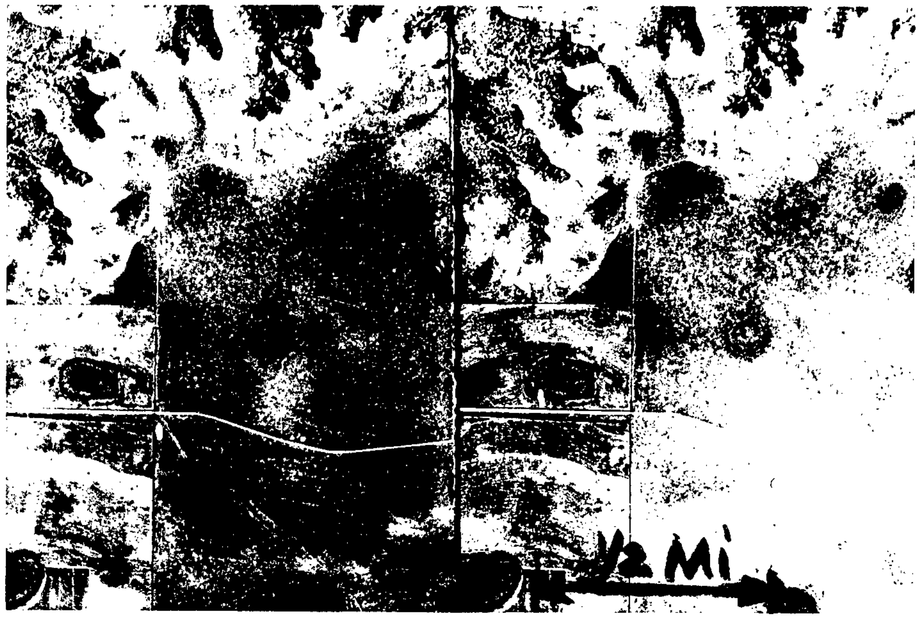


FIGURE 92.—*Stereophoto of Part of the Boundary Between the Great Plains Mantle and the Underlying Sandstone and Shales.* The broad sloping white fringe represents erosion confined to the loosely cemented mantle. The sharp break, or prominent ridge, is the upper sandstone member of the underlying rocks

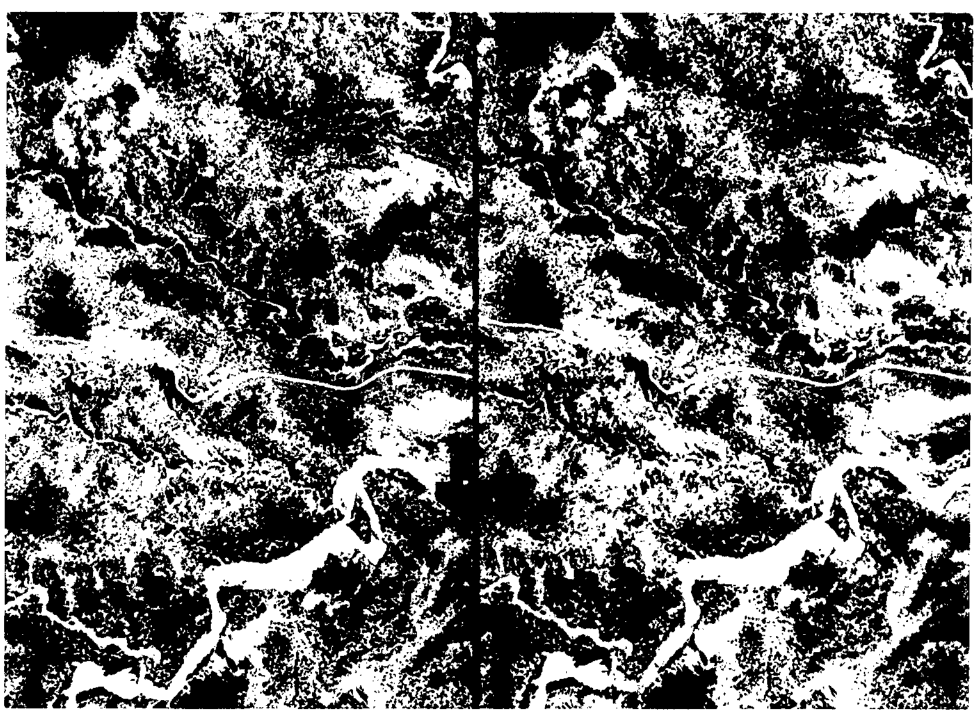

FIGURE 93.—*Stereophoto of the Pattern of the Underlying (denuded) Sandstones and Shales (Triassic).* The harder sandstone ledges produce such erosional features as flat-topped mesas or buttes, vertical columns or pinnacles, waterfalls, and angularity in drainage features.

FIGURE 94.—*Great Plains Gully in Cemented Cap Material.* This is a stereophoto of a gully system which is denuding the Great Plains area. This photograph illustrates the relationship of gully shapes and gradients to the soil texture. Headward erosion is in the loosely consolidated, granular mantle.

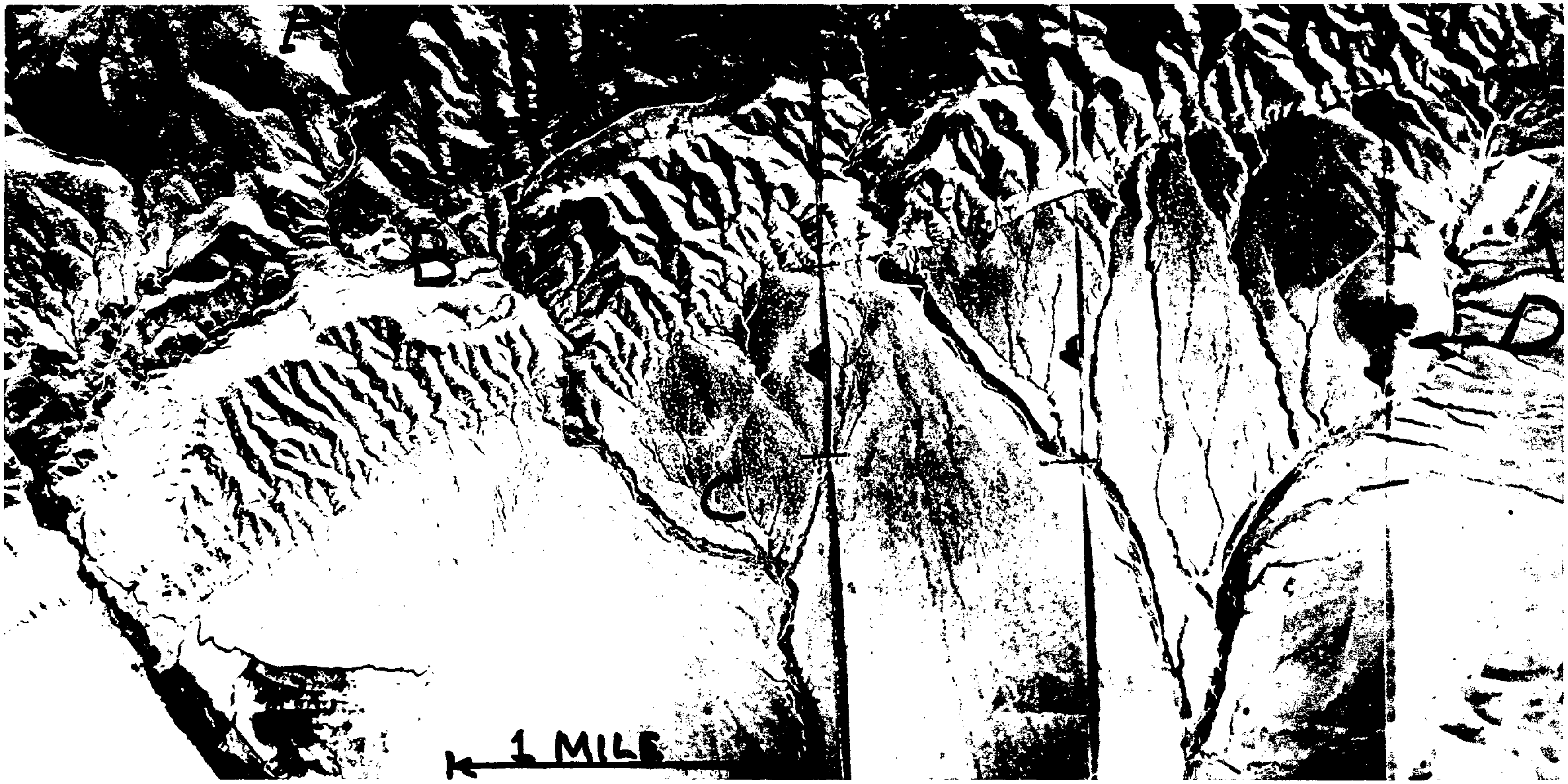


FIGURE 95.—*A Pattern Containing Valley Fill—Uplift, Erosion, and Redeposition in the Relatively Quiet Waters of a Lake.* This Montana photo shows all of the steps necessary in the development of these conditions. Area *A* contains the pattern of the intrusive granite material which may have been responsible for the uplift. Area *B* is a broad band of uplifted, strongly tilted sedimentary sandstone and shale rocks. Area *C* is a broad, level, expanse of sloping beach, shore, or lakebed composed of redeposited material from areas *A* and *B*. Area *D* contains two isolated rocky areas which are nearly buried by the alluvial materials. The airphoto interpretation of each area is as follows: Area *A*—jointed, rugged, lack of symmetry, and quite rocky as well as elevated; area *B*—lineal arrangement of the ridges and erosional features, trellis-type drainage pattern, hogback ridges, and a characteristic erosional feature for both the sandstone and shale members; area *C*—a sharp lineal break between *B* and *C*, flat and gently sloping land form of a lake shelf or beach, and a general parallelism in the more recent erosional features of the lake area; area *D*—knob-like land form, vegetative cover, and angular structure.

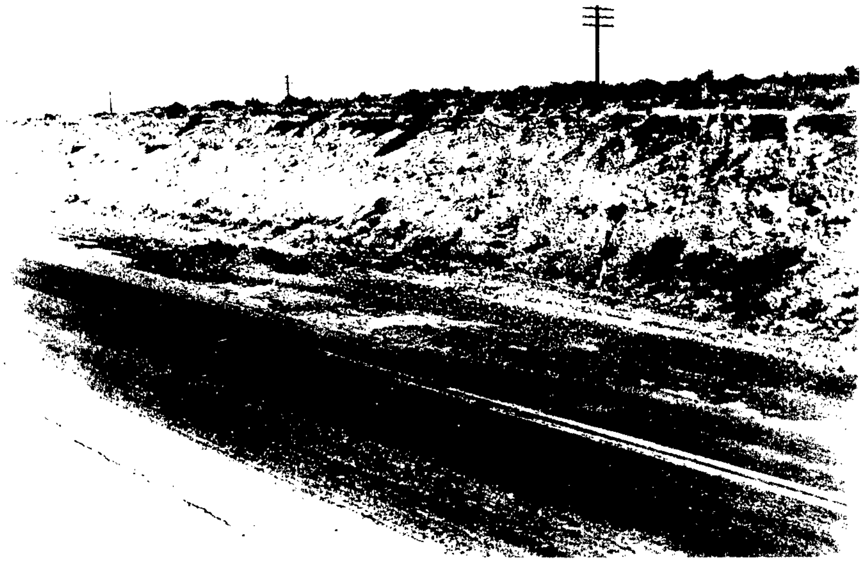

FIGURE 96.—*Highway Cut in a Portion of an Alluvial Fan* (*valley fill*). Note the granular nature of the sediments. In this particular instance the cut exposed granular material on clay of a previous valley flow. The pavement rests on this clay (Nevada).

FIGURE 97.—*Tertiary Lakebed Influence.* This lakebed remnant occupies a terrace position (western Nevada).

FIGURE 98.—*Semiconsolidated Tertiary Lakebed Sediments in Nevada.* This consists of stratified sands, conglomerates, and silt which have been cemented to form weak sedimentary rocks.

FIGURE 99.—*View of the Great Salt Lake Desert Border in Utah.* This is the remnant of a Pleistocene lake.



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